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RESEARCH AND DEVELOPMENT IN MANITOBA MINES
COMMUNICATION SYSTEMS FOR ISOLATED AREAS IN MINES

FINAL REPORT

Prepared for

Canada Centre for Mineral and Energy Technology

(CANMET)

By:

Hudson Bay Mining & Smelting Co., Limited

Ruttan Operations

LEAF RAPIDS, Manitoba

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Submitted by
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Ruttan Division
LEAF RAPIDS, Manitoba

Work on the project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada under the Canada/Manitoba Mineral Development Agreement.

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ABSTRACT

Rapid, instantaneous transmission of voice and data in an underground mining environment may have the potential to improve safety and increase productivity.

A research project was undertaken to determine the practicality of systems in an underground environment in the fields of voice communications, mobile equipment data transmission, rock mechanics monitoring and hoist communications.

A study by Falconbridge Limited concluded that a medium frequency FM (Frequency Modulated) radio offered the best potential for underground communications and their report recommended a system built by Montan-Forschung of West Germany; this system was purchased.

EXECUTIVE SUMMARY

The implementation of a research project covering the facets this one did suffered from a lack of continuity from inception. There was a need to be more specific in what was expected from two of the systems. Only two of the sub-projects were totally successful, and this was due to the fact that they were designed with specific specified needs (rock mechanics and hoist radio).

The voice radio system is hindered with a single inherent problem. That is, the need for a single wire antenna strung along tops of drifts. Presently, this antenna is subject to blasting damage from sulphide explosion causing daily maintenance to provide communications. This problem would only occur in underground mines where the environment is subject to sulphide gas explosions. It is suggested that more research is needed to enable a radio system to use the existing pipe work (ie. air lines) as an antenna. Also, the implementation of any new system causes personnel to have a "resistance to change". As the need for improved communications did not come from the users, but rather was input on them from above, the use of the system met a number of obstacles.

The mobile equipment data monitoring system requires a number of modifications to ensure that it will provide useful productive data flow. The changes include need to be able to record what stope the unit is mucking from, and to produce an accurate report of tonnes trammed by stope, hours operated, hours delay, hours mechanical downtime. This project area also had the largest factor of resistance to change from workforce. The use of mobile monitoring equipment of the type listed, with modifications, could improve reporting procedures and improve productivity.

The rock mechanics area of the project was completely successful and all expectations were proven. Data can be logged on rock movements and be recorded at a surface site on a personal computer.

The hoist radio system also proved to be successful and provided a secondary means of communication between hoistmen and those carrying out repairs and inspection of compartments.

ACKNOWLEDGEMENTS

The basic communications system is being sent to HBM&S, Namew Lake property where due to a single level, production and an atmosphere where sulphide type explosions are less likely, it is felt the system can be better used. The hoist radio system is being kept at the Ruttan mine site.

Work on the project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology; Energy, Mines and Resources Canada, under the canada/Manitoba Mineral Development Agreement.

The autor would also like to express his gratitude to Hudson Bay Mining and Smelting Co., Limited and Sherritt Gordon Mines Limited.

Sincere thanks are extended to Mr. M. Kirby, General Manager and Dr. Somchet Vongpaisal of CANMET for their co-operation and continuous assistance on all aspects of this study.

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1. INTRODUCTION

In the interest of improving productivity and safety at Ruttan Mine, it was felt that substantial gains could be made through the use of improved communications. To provide improved and effective communications, a research and development agreement was entered into with CANMET. The areas of interest include voice communication for operations and maintenance personnel on mobile equipment, data communications for mobile production equipment, remote monitoring using a radio system, and voice communications in the shaft.

The project consisted of two phases. During the first phase a subcontractor was employed to gather technical information and publications, visit a number of mines to evaluate their communication systems, and to recommend systems for field trials. The results of their research are available in publications from CANMET and CIM (references 1 to 3). The second phase was to purchase and install the recommended systems at Ruttan and to evaluate their performance and effectiveness. The subcontractor's research concluded that a hoist radio system should be separate from any other mine-wide radio system, therefore two separate voice systems were used; one for the hoist and another for a mine-wide system. The mine-wide voice system which was recommended was also capable of providing data communication from mobile equipment, therefore it was decided to evaluate its capabilities as well. In addition, it was also felt that there was a need for a monitoring system which could be used in remote locations serviced by the radio system but not having electrical power. Therefore, four systems were chosen for evaluation during this second phase; a hoist radio system, a mine-wide voice radio system, a data system for mobile equipment and a battery powered unit for rock mechanics monitoring.

2. VOICE RADIO SYSTEM

The underground radio system is intended to provide voice communication for operators of mobile equipment and for personnel in areas where telephones are not installed.

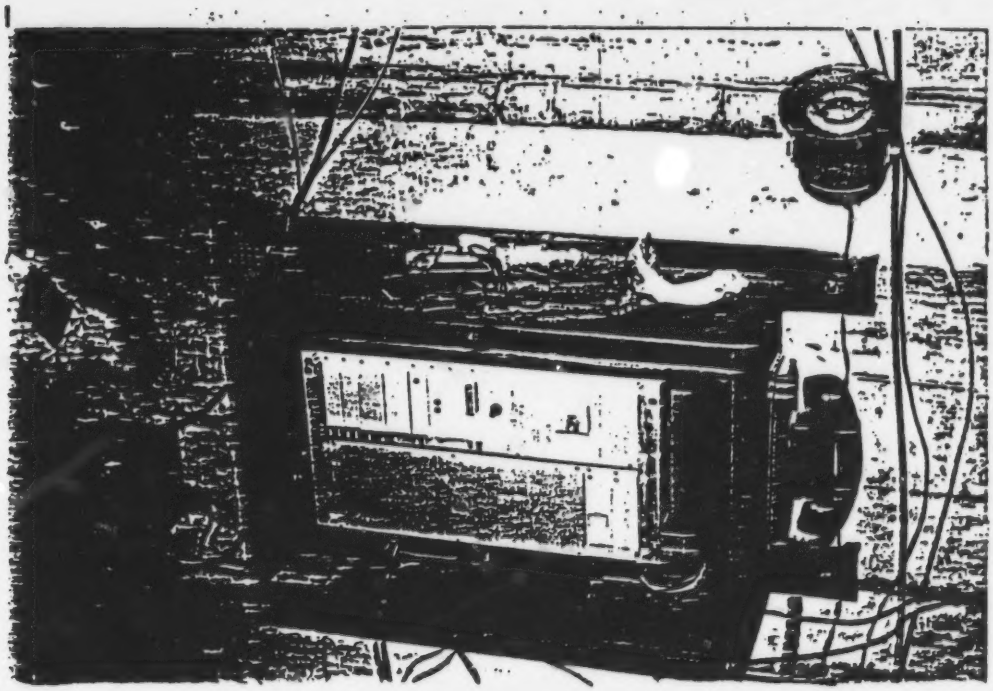
The system under evaluation at Ruttan Mine is built by Montan-Forschung in West Germany. The system consists of mobile and portable radios, a base station and an antenna system. The radios are frequency modulated and operate in the medium frequency band.

2.1 Base Station

The base station, Figure 1, is supplied with a loudspeaker, a handset and two waveguide ohmmeters. The base station operates as an automatic repeater station. It receives a signal at 430kHz from a mobile or portable radio and retransmits it at 290kHz to the other radios. In addition the base station is equipped with a handset and loudspeaker thus allowing a person to communicate directly from the base station.

The base station also transmits call tones and end-of-transmission tones. When the base station receives a momentary signal, such as when a push-to-talk button is pushed momentarily and released, it will transmit a call tone, actually a series of tones (beep-beep-beep-beep). If the base station receives a longer duration signal, such as would be transmitted when someone talks, it will transmit a short tone (beep) after the transmission ends. The end of transmission tone is a convenience but the call tone lasts too long and tends to be annoying.

Figure 1 - Base Station Speaker (top right)
- Wave Guide Ohmmeter (left)
- Base Station With Cover Removed (centre)



2.2 Antenna System

The waveguide ohmmeters are used to monitor the impedance of the antenna system. When a pushbutton on the side of the ohmmeter is pressed the impedance of the antenna system, in ohms, is indicated on the meter. The system is designed to operate with an antenna impedance of 300 ohms, therefore the antenna must be installed and terminated so as to achieve an impedance of 300 ohms or thereabouts. A certain degree of experience is required to terminate the branches of the antenna system to ensure an adequate signal strength in all areas.

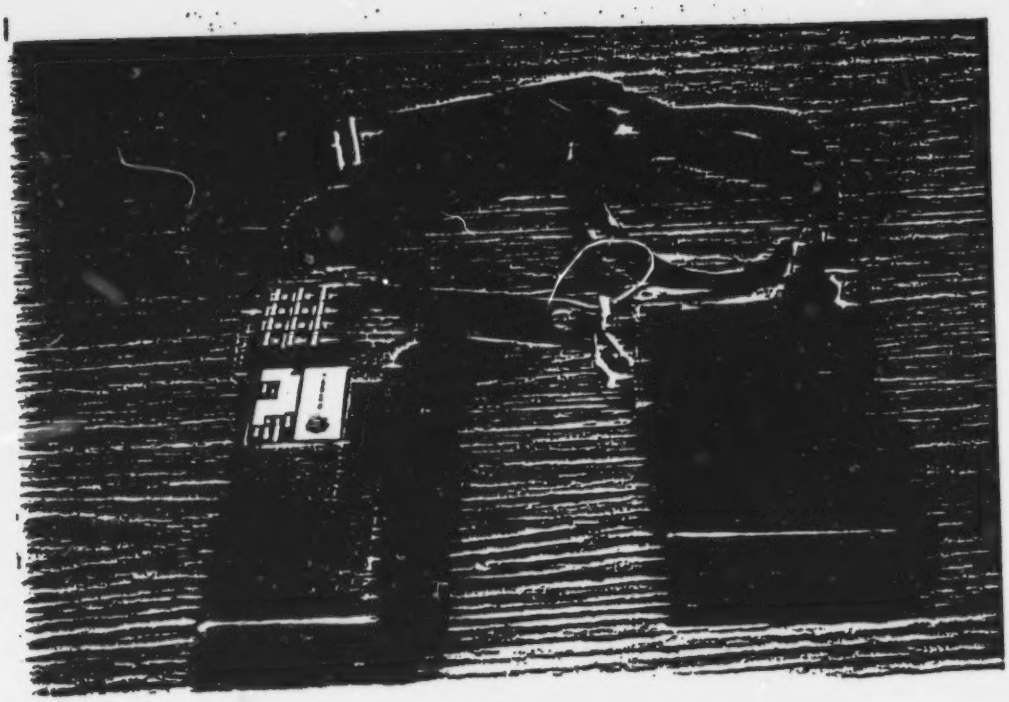
The antenna consists of a single conductor insulated wire which can be installed as a closed loop or as two branches which are terminated by resistors to ground. An inexpensive #12 gauge type TWH wire was used. The antenna wire was fastened, using fence staples, to tapered wooden pegs which were driven into holes drilled into the back of the drift. The manufacturer recommended that the antenna be installed, wherever possible, about one foot away from metallic objects such as pipes and other cables, therefore it was necessary to drill a new set of holes throughout the areas where the antenna was to be installed. The pegs were driven into the new holes and the antenna wire stapled to the pegs, a simple but time consuming process. Having to drill a new set of holes in the drifts also requires a large commitment of time.

2.3 Battery-Powered Handsets

The portable radios are hand-held, Figure 2, with a shoulder strap and have an on-off switch, a push-to-talk button and a keypad for selective calling. They transmit, at 430kHz, to the receiver in the base station and receive, at 290kHz, signals transmitted from the base station. Since they transmit and receive at different frequencies, portables (and mobiles) cannot communicate directly from one to another. All signals must go through the base station.

Having so few controls, they are easy to use, once the user is familiar with the selective call procedure. The batteries should be changed and recharged each shift. Changing batteries is a simple procedure. The auto output of the portables is somewhat low and they may be difficult to hear in noisy locations. The selective call tone is much louder and is accompanied by a flashing LED for visual indication.

Figure 2 - Portable Radio



2.4 Mobile Radio System

The mobile radios consist of two units; an antenna unit and an audio unit, Figure 3. The audio unit has an "on-off" switch, a "power on" light and a volume control. A loudspeaker and a microphone with a push-to-talk button and a keypad for selective calling is also provided. The mobile radios operate at the same frequencies as the portable radios. Installation was sometimes a problem. Altogether it is necessary to install an antenna unit (in a location where it is exposed to the antenna wire), an audio unit (in a location where it is accessible to the operator), a loudspeaker (in a location where it will not be damaged), a relay for the selective call feature (if desired)

and a light for the selective call feature (if desired). Some vehicles, particularly scooptrams, have limited free space available in which to mount components where they are both safe from being accidentally damaged, and easily accessible for installation, operation and maintenance. In contrast to the portable radios, the mobiles have sufficient audio output for all but the noisiest vehicles. In those cases the vehicles can be equipped with selective calling although this entails additional cost and complexity.

Figure 3 - Mobile Voice Radio Components
- . Speaker (top)
- . Amplifier (left)
- . Antenna (right)
- . Microphone with keypad for selective calling (bottom)

2.5 System Installation (Figure 4 shows the longitudinal section of the Ruttan Mine)

The equipment at Ruttan Mine consists of one base station, seventeen mobile radios and six portable radios. The base station is installed in an electrical substation on 730 meter level of the mine. The antenna consists of 2 legs, one extending from the base station up the vehicle ramp to 660, 620 and 550 meter levels, and the other extending from the base station down the shaft to 800 meter level. On each level, there are shorter branches which extend into the main haulage drifts. The mobile radios are installed on scooptrams, Figure 5, on shifter's jeeps, and on the mechanic's and electrician's jeeps, Figure 6.

Figure 4 - Longitudinal Section, Ruttan Mine

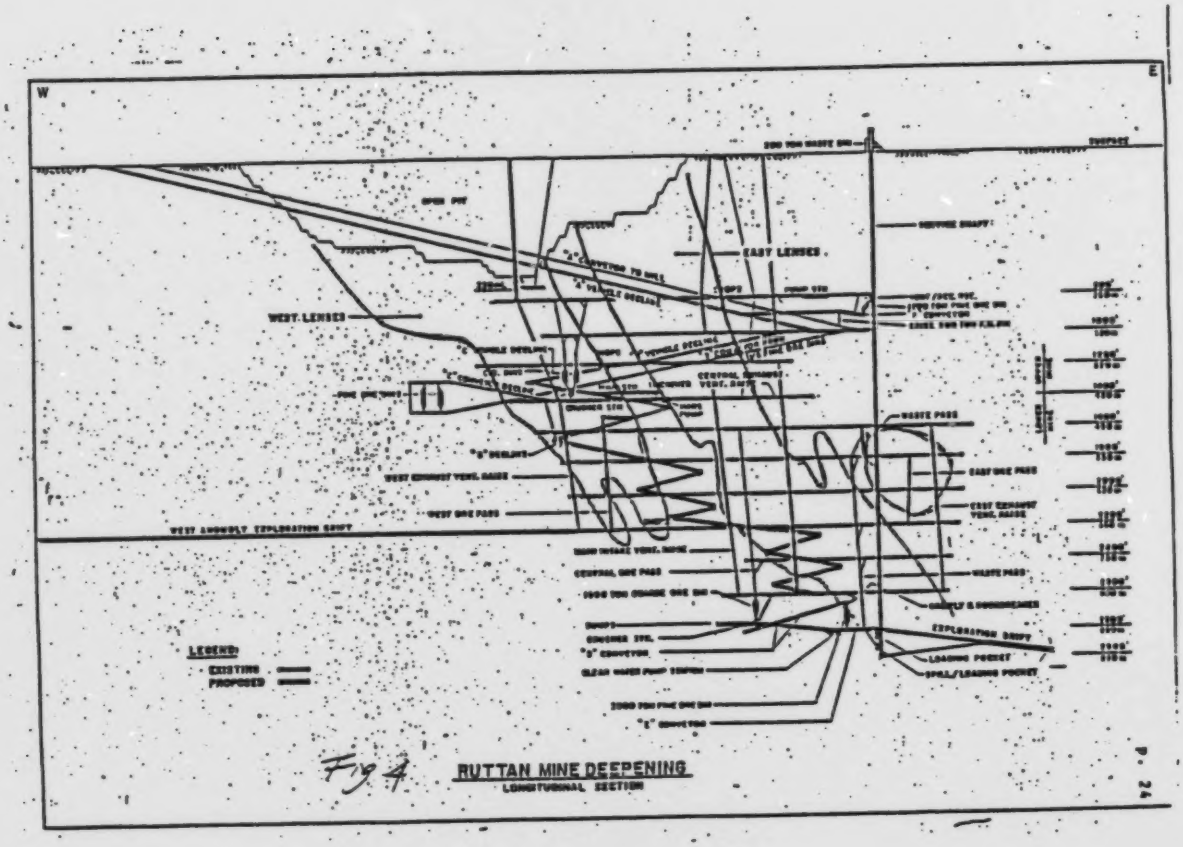


Figure 5 - Voice Radio Installation on Scooptram
. antenna and amplifier are both mounted on one common bracket

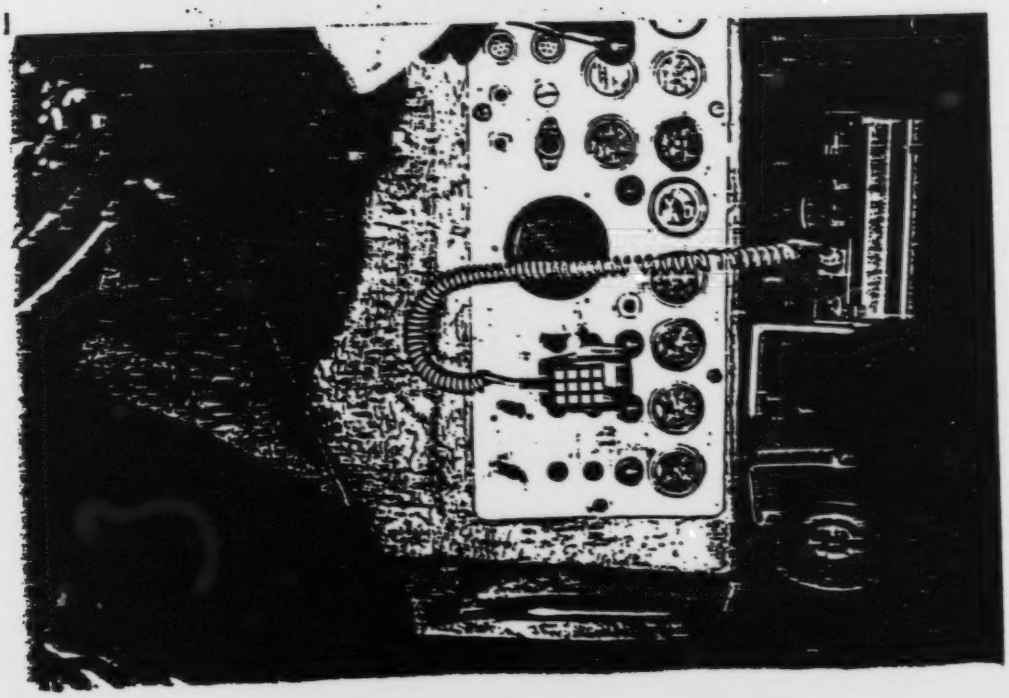
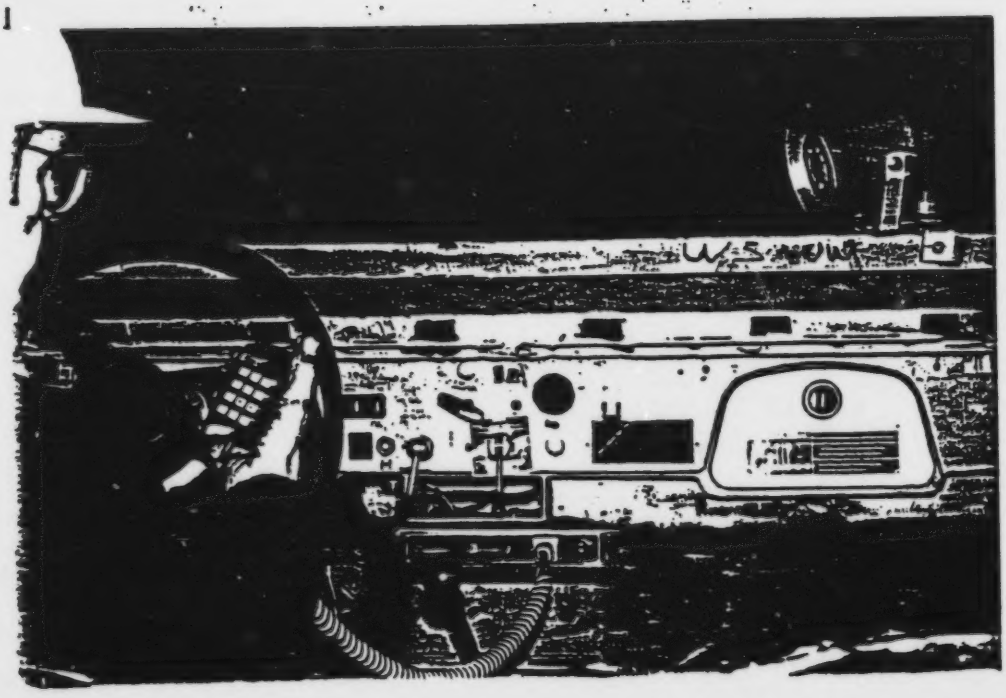


Figure 6 - Voice Radio Installation on Electrican's Toyota
. amplifier (blue) is mounted under dash
. speaker is shown in top right corner
. operator is holding microphone
. antenia is mounted on top of vehicle (out of picture)



The selective call feature allows the person who is initiating a call to signal the particular radio which he wishes to contact. The caller pushes the push-to-talk button and "dials" the desired number on his touch tone keyboard, thus transmitting a sequence of tones to all the other radios. Each radio has a tone decoder which is wired to recognize a particular sequence of tones, and which will give an audible and visual (with the addition of a light) indication when it receives its particular code. All other radios receive the tones but do not give any indication. The selective call number for each radio must be hard wired into the decoder when the selective call feature is installed. Therefore the desired number must be decided upon when the radio is ordered and it is somewhat difficult to change numbers as would be required if a radio is replaced in the field.

On the mobile radios, the original microphones were replaced with ones which had a built in touchtone keyboard. However, the new microphones have demonstrated a tendency to fail due to getting wet when the vehicles are washed. The microphones should be removed during washing, a task that is often forgotten. The selective call visual indication operates in such a manner that it switches the light on and off, giving the appearance of a flashing light. The relay is required to control the larger current draw of a light which the selective call decoder cannot handle. If the relay and light could be built-in to the radio, it would help to simplify installation as well as reduce the number of external components which may get damaged.

The portable radios have a small keyboard on the front of the radio and a flashing LED on the top of the radio for visual indication. It should be noted that the selective call system on the radios at Ruttan Mine was designed and retrofitted into existing radios by IMS Electronics. Newer radios with selective calling direct from Montan-Forschung have a revised selective call system. The mobile radio has a different microphone and keyboard arrangement and the selective call number of a radio can be changed more easily.

2.6 Performance

The underground voice system has met with only limited success. The system is quite capable of providing good communications but a number of factors detracted from its total success. Maintenance of the system is crucial to its acceptance and success. The antenna is a critical component of the system and, if it is damaged, communication can be lost or very limited. Any damage must be repaired immediately or the system will not be accepted due to unreliability. Similarly, radios which malfunction must be repaired or replaced to ensure constant availability of communications. Personnel must be trained to make repairs to the system and maintenance of the system must be a high priority.

Ambient noise is another major problem. Unlike most vehicles used above ground, which have enclosed cabs, underground vehicles generally have open cabs and the operator is subject to very high noise levels which may prevent the operator from being able to hear incoming calls. The use of a selective calling feature is helpful in overcoming this problem. Some newer vehicles are being constructed with enclosed cabs and this may help to alleviate the problem of ambient noise. Another possible adaptation could be the use of headphones built-in to earmuff type hearing protection, if people are willing to use them.

The radios and all accessories must be very rugged and virtually waterproof. All wiring connections should be made using sealed connectors to prevent water from getting in and plug in connectors to simplify installation. The connectors should be of a type which are resistant to vibrating loose.

In comparison with above ground radios, underground radios must operate in high ambient noise conditions, very dirty and wet locations and in an environment which is not conducive to the propagation of radio signals. In the case of the Montan-Forschung radios, they are very expensive, although that may be the price to be paid for radios which will operate under those conditions. Acceptance of radios in a workplace where they have not traditionally been used is also a concern. It is not sufficient to assume that it will be used just because it is there. People must want and need a radio system or it will not get used, regardless of how well it may perform. In addition, people who, in their regular work, do not often need to communicate with others are not going to make much use of a radio. To try to ensure maximum use of radios, some thought should be given to which persons must often communicate with others and equip those persons with radios first. However, with suitable solutions to those problems, there should be no reason why an underground radio system could not be just as useful as an above ground system.

3. MOBILE EQUIPMENT DATA SYSTEM

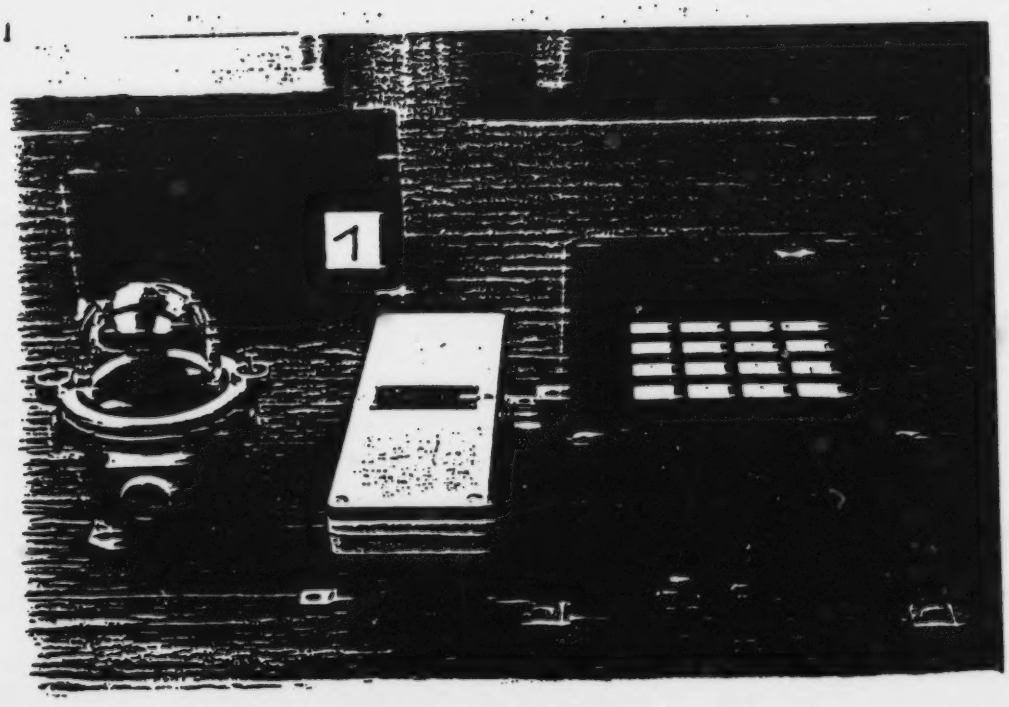
The data system is intended to provide data communications from mobile equipment to a central monitoring location. It is also built by Montan-Forschung and shares some components of the voice radio system.

The system uses the same radio base station and antenna as the voice system, with the simple addition of circuit boards for the data system. The other components of the data system are: a personal computer, an interface computer which collects data from the mobile equipment and data equipment mounted on the mobile equipment and in the mine. The interface computer polls each vehicle individually by transmitting a request for data over the radio system. The data equipment on the vehicle sends back the required information when it is polled. The interface computer passes the information it receives to the personal computer for analysis and storage.

3.1 Data Equipment

The data equipment mounted on the vehicle consists of a "smart" keyboard and a data transceiver, Figure 7. The keyboard has a number of buttons which correspond to the various operating conditions of the vehicle such as hauling ore, hauling waste, shutdown for service, broken down, etc. There are also buttons with which the operator can enter a single digit number (which could correspond to a workplace, for example). The operator pushes the key or keys which correspond to his activities while he is working and that information is stored in the keyboard memory, to be sent to the interface computer when requested by the interface computer.

Figure 7 - Data System Mobile Components
. keyboard (right)
. antenna (centre)
. infrared receiver (left)
. infrared transmitter (top left)



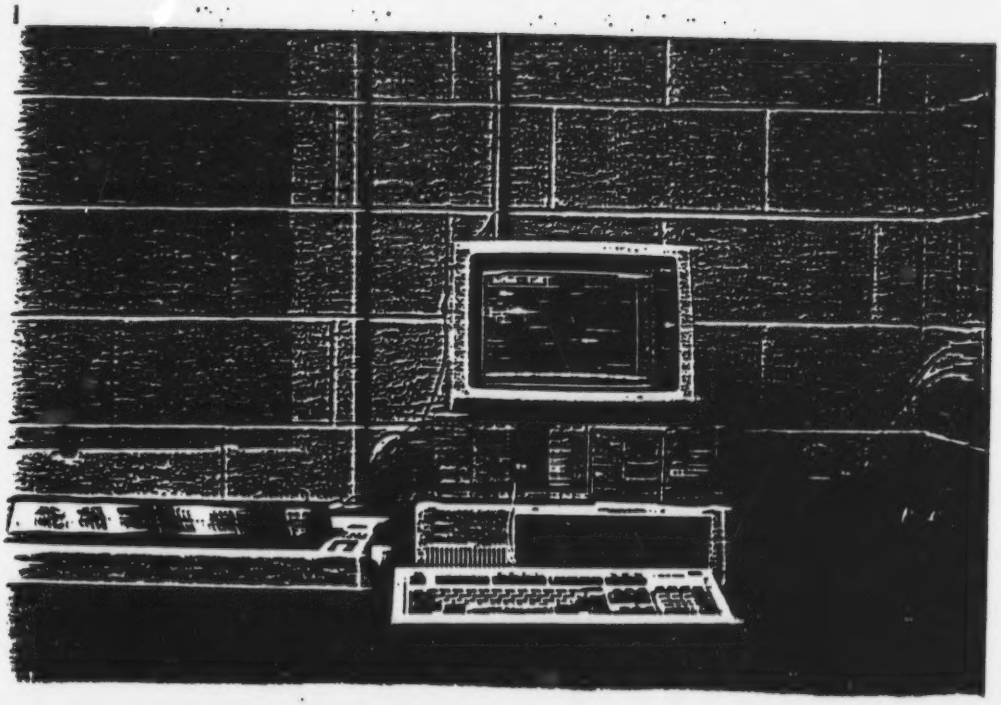
3.2 Interface Computer

The interface computer controls the collection of data from the vehicles. It sequentially polls each vehicle and requests the data that is in the keyboard memory. The interface computer sends its request over a telephone cable to the base station, where it is transmitted to the vehicles at 593.5 kHz. The vehicle being polled then transmits its data back to the base station at 190kHz and then to the interface computer via the telephone cable. The interface computer displays the data from each vehicle as it receives it and is capable of operating on a stand-alone basis. It is also capable of communicating with a personal computer to permit storage and further processing of the data.

3.3 Data Display System

The personal computer is used to store the data and to display it in an understandable and useful form, Figure 8. The computer is programmed to request data from the interface computer and save the data on a disk file. It also creates displays to show the status and operation of each vehicle over the preceding eight hour period and to show the accumulated hours for each mode of status and operation for the month-to-date. There is also a test mode which displays the raw data as it is received from the interface computer.

Figure 8 - Data System
. printer (left)
. color monitor (top)
. Montan-Forschung interface computer (centre)
. IBM PC-XT and keyboard (bottom)
. mobile components (keyboard, IR devices - right)



A hard copy printout of the accumulated hours, in either a table or bargraph form, can also be obtained (Figures 9 and 10). The computer is dedicated to the data system and is unavailable for other purposes when the data system is running. A system in which the data program runs in the background would be convenient. The software is derived from an existing program and modified to suit the application.

Therefore, you must know what you want from your system before you order it. As part of the planning process, prior to ordering, it is essential to document, in detail, the requirements of the system. This must include what information is to be shown in charts, graphs and reports, as well as their format and layout. This information can then become part of the purchase requirements to allow the vendor to design the software to suit the application.

Another feature of the system is the capability to monitor the location of equipment. This is accomplished by having the vehicle "check in" when it reaches selected locations, Figure 11. At these locations an infra-red transmitter is mounted in the drift. Each transmitter transmits a coded signal, which is received by an infra-red receiver on the vehicle as it passes the transmitter. The code is sent to the interface computer and then to the IBM PC which is programmed with the location of each infra-red transmitter and its code. When the computer receives a position code from a vehicle, it can then relate the position of that vehicle to the location of the infra-red transmitter and display the vehicle's location on a graphic display of the mine. By keeping track of the sequence of location reports which a vehicle sends back, the computer can also determine which direction the vehicle is travelling in.

Figure 9 - Accumulated hours for each mode of status and operation for each vehicle. A separate table is created for each month.

Vehicle 1 - 5 Hours In Month 04/87 11:39:30

VEH.	SERVICE	REPAIR	SHUTD.	STARTUP	OPER.	SURFACE	U/G	WASTE	ORE
1	3.95	5.65	2.28	8.98	36.32	0.25	5.98	16.97	33.98
2	54.38	0.00	0.00	0.00	0.00	54.38	0.00	0.00	0.00
3	54.38	0.00	0.00	0.00	0.00	54.38	0.00	0.00	0.00
4	54.38	0.00	0.00	0.00	0.00	54.38	0.00	0.00	0.00
5	54.38	0.00	0.00	0.00	0.00	54.38	0.00	0.00	0.00
	221.48	5.65	2.28	8.98	36.32	217.78	5.98	16.97	33.98

Figure 10 - Bargraph display of accumulated hours for each mode of status and operation for vehicle #1. Separate graphs are created for each vehicle.

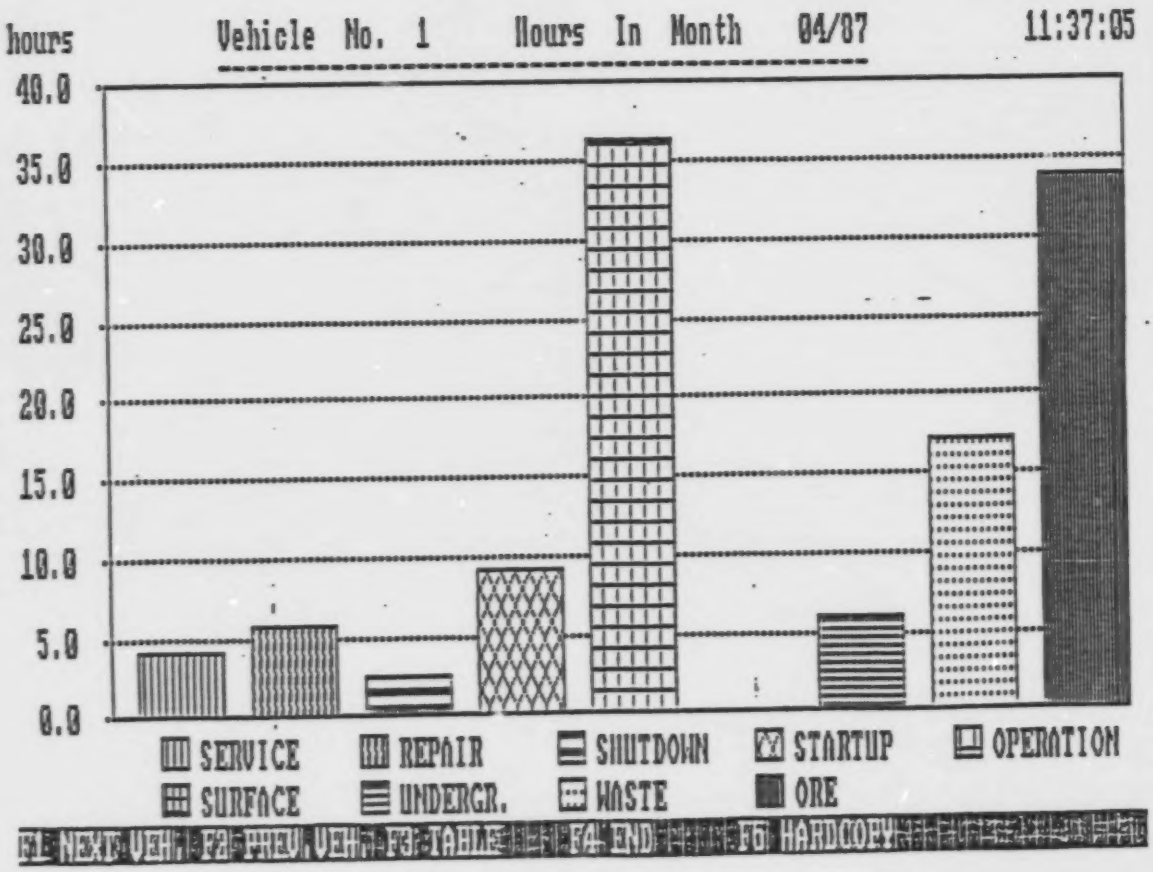


Figure 11 - Graphic display of mine layout of levels where data system will be used (730mL and 800mL

3.4 System Installation

Installation of the data system is not complete and only a preliminary evaluation is currently available, based on initial testing of the components. Operator acceptance may be hard to achieve since the system is monitoring their work and activity. Operator co-operation and training will be an important factor in the implementation of the project. The operator must be trained and be willing to use the equipment properly or the system will not work.

The radio system is an essential component of the data system. It must be installed in all areas where the data system is to be implemented and must be kept operating if the data system is to work.

A careful evaluation of the need for this type of system and of the specific requirements of its application, is essential to the successful implementation of a project of this type.

4. ROCK MECHANICS MONITORING UNIT

The rock mechanics monitor is intended for use by our Geology Department to provide remote monitoring of extensometers. The monitoring unit was designed and built by IMS Electronics and operates in conjunction with the Montan-Forschung radio system. It is intended to be used in remote locations which are serviced by the radio system, but which may not have electric power available. It is battery operated and has a timer which causes the unit to power up, transmit the data and then power down until the next cycle. The frequency of operation can be easily changed to as often as every 17 seconds or as long as every 40 hours.

The unit takes up to 16 analog input signals in the range of 0 - 10 V.d.c., converts them to digital values and transmits them as a modem signal over the audio channel of the radio system to the base station. The data being transmitted is heard as a burst of noise lasting about 2 seconds. From the base station, the signals are sent over a hardwired circuit to a Radio Shack TRS 80 Model 100 computer having a built-in modem, which recovers the original input signals. The signals can then be processed, displayed, or stored as required (see detail in Appendix A).

4.1 System Installation

The extensometer converts longitudinal motion of the extensometer rods in a drill hole, to rotary motion of a potentiometer in the extensometer head, through the action of a rack and pinion gear system. The potentiometer thereby provides an output voltage which varies with movement of the extensometer rods. The rock mechanics monitor then measures the output voltages and transmits them to the computer.

The computer receives the data and has a program to calculate the relative movement of the extensometer rods. This information is printed along with the data and time of the readings (see Figure 12).

The system works well except when there is noise on the radio system which causes data errors. When the computer detects data errors it simply ignores the data and waits until the next transmission comes along. It is therefore critical that the radio system be operating properly or you may never get any useful data.

While the system works quite well using the Radio Shack TRS-80, Model 100 computer as a stand-alone system, it could be convenient to be able to integrate it into a larger system.

4.2 Performance

The original and primary application of the unit is to monitor analog extensometers as part of a rock mechanics project in progress at Ruttan Mine. However, through the use of appropriate transducers and sensors, which convert physical conditions such as temperature or pressure to analog signals in the range of 0 - 10 V.d.c., a variety of conditions can be monitored using the same unit.

The unit should be very useful for on-line monitoring of conditions in remote locations which might ordinarily be checked only infrequently. Acceptance should not be a problem since it will relieve personnel of a time consuming task and will provide data on a much more frequent basis. However, since it depends on the radio system, reliability of the radio system will be an important factor in its usefulness.

Figure 12 - Printout of rock mechanics monitor readings

07/09/87 08:26:40
CH. 1 .3
CH. 2 6.55
CH. 3 41.01

07/09/87 09:03:4a
CH. 1 .3
CH. 2 6.68
CH. 3 41.01

07/09/87 14:38:10
CH. 1 .3
CH. 2 6.55
CH. 3 41.11

07/10/87 09:12:33
CH. 1 .43
CH. 2 6.68
CH. 3 41.11

07/10/87 14:09:49
CH. 1 .04
CH. 2 6.68
CH. 3 40.91

07/13/87 07:50:28
CH. 1 .17
CH. 2 6.68
CH. 3 41.11

07/13/87 08:27:49
CH. 1 .3
CH. 2 6.68
CH. 3 41.11

07/13/87 14:39:19
CH. 1 .3
CH. 2 6.68
CH. 3 41.01

5. HOIST RADIO SYSTEM

The hoist radio system is intended to provide voice communication and signalling between the hoist room and the conveyances. The radios are manufactured by Femco in the U.S.A. and distributed by National Mine Service in Canada (see detail in Appendix B).

The system at Ruttan Mine consists of two units; a Trolleyphone (base station) and a Cagephone (mobile radio). The Trolleyphone unit is intended for permanent installation and is complete with a loudspeaker, a microphone, a push-to-talk footswitch and a pushbutton for signalling which transmits an audio tone to simulate the sound of a signal buzzer. The Cagephone unit is a portable radio and has a built-in microphone and speaker, a push-to-talk button and a signalling button. The radios operate at 88kHz and are frequency modulated.

5.1 System Installation

The fixed Trolleyphone is installed in the hoistroom or headframe and its antenna is mounted beside the hoist rope just below the sheave wheel in the headframe. The Cagephone is carried or mounted on the conveyance and its antenna is attached to the hoist rope at the conveyance. When one radio transmits, its antenna induces a radio signal into the hoist rope which in turn induces a signal into the receiving antenna at the other end of the rope.

The system under evaluation at Ruttan is still in its final stages of installation and commissioning, and although it has seen very little service, it has undergone a considerable amount of testing. Sound quality is very good. The radios have signalling and voice capabilities, which are both essential for a hoist system. However, they do have some inconveniences.

Smaller, lighter portables would be easier to use during shaft inspection. The Cagephone is fairly large and heavy, and is awkward to use as a portable radio. It has a combination speaker/microphone on the front of it and if it is not permanently mounted at face level you must pick it up or bend down to use it. We have connected a handset with a push-to-talk button and it works very well.

The Trolleyphone and its accessories are connected by prewired plug-in connectors. This results in a simple, foolproof installation, but it also creates a congestion of wires around the hoistman's control panel. The signalling feature should allow the person who is sending the signals to hear his own signals as an audible verification. The Trolleyphone's push-to-talk button must be pushed in order to use the signal button, an inconvenience. The Trolleyphone signals should work without having to key the transmitter separately.

Installation of the antennas under the sheave wheels was more difficult than one would have expected. There is only limited space to work and access is awkward. The antennas usually need to be removed when any major work, such as changing sheave wheels or hoist ropes, is performed.

Very little information regarding installation, maintenance, adjustments or repairs was provided with the radio. Installation, operation, and maintenance manuals would be very useful.

Similar radio systems are available which have the capability of monitoring for open door, slack rope, etc. Ideally, it would be desirable to have a system which uses only one antenna, of some type, to communicate to all conveyances and compartments, and which would have multi-channel, voice, signalling, monitoring and control capabilities.

6. CONCLUSION

Communication systems cover a broad and diverse spectrum of systems and applications. While this project was aimed at radio communication systems, an hard-wired system should not be forgotten or ignored. There are many applications where hard-wired systems would be less expensive to purchase, easier to install and more reliable. Installing an antenna system, which should be kept physically separated from existing wiring, requires drilling new holes in the drift, hardware for mounting the antenna and the required labour. Installing a data cable can usually be a matter of the labour required to hang the cable with existing wiring. An antenna wire by itself is much more succeptable to getting damaged than a data cable in amongst a large bundle of cables. A radio system, however, is the only practical form of communication with mobile equipment and should be used when an application requires it. Regardless of whether a communication system is a hard-wired or radio type or used for voice, data or control there will be benefits related with it. Some benefits may be real and immediate whereas others may be less tangible and apparent only after being in service for some time.

The benefits of the hoist radio stem from the availability of a second form of communication in the shaft; in addition to the signals. Voice communication gives a form of security by being able to talk to someone in case of problems or emergencies. Signal systems with switches and pull cords occasionally malfunction and the radio can provide an alternative signal system to replace the regular system while it is being repaired.

The possible benefits of the underground voice radio system include increased productivity and safety. Faster communication with maintenance personnel could reduce downtime, increase equipment availability and improve productivity. An additional benefit in that personnel working alone or in isolated areas could have immediate communication in the event of emergencies.

The data system could provide reports which contain the same information as the operator provides on his operators report each shift and would therefore eliminate the task of filling in a report sheet. More detailed monitoring of vehicle usage, such as operating, idle or shutdown hours, could be automatically provided. Instantaneous monitoring of production could be is another benefit. As experience with the system is gained other benefits may be realized.

The rock mechanics monitor unit was used to monitor extensometers. Its major benefits was an increase in monitoring frequency and the relief of personnel from a time consuming task. Its general purpose could make it useful for any number of applications where monitoring of trends over a long period of time is desired.

This project suffered from a variety of difficulties. The project was "too much-too soon". Installation of four systems in such a short time with only existing personnel requires a great commitment of time. Regular production must be a priority and most of the project work is done whenever time is available. Therefore the work takes a long time with many delays, unless there is a serious commitment to the project. Since three of the systems all depend on the radio system, it is essential to get the radio system operating reliably and accepted before starting other systems which depend on it.

In the area where the radio system is installed, the orebody is not very spread out. Consequently, if a vehicle breaks down the operator simply goes to the lunch room (refuge station) which is not very far away, telephones the shop and waits there until the vehicle is fixed. The time gained by having a radio is only the time required to walk to the lunch room, which is not very long. By comparison, a much longer time is usually lost waiting

for someone to make the repairs. Some people seemed to feel that the small savings in time did not justify the use of radios.

There was a certain amount of disinterest, probably brought about by a lack of need of these systems. Ruttan Mine already had a very extensive pager telephone system as well as standard telephones connected to the Manitoba Telephone System switchboard. The pager telephone system is installed in all locations with stationary equipment and the loudspeakers are audible for a long distance if the ambient noise level is not too high.

In addition, a very near shutdown of the mine decreased the amount of use of the communication systems. Many of the vehicles equipped with radios were not in service and the system was not being used. As it wasn't being used, what little interest there was soon faded away.

Probably most important is the requirement to evaluate the need for any particular system and, secondly, to evaluate the requirements for a system, so that it does what you want it to do.

REFERENCES

1. CANMET — "Research and Development in Manitoba Mines, Communication System for Isolated Areas in Mines, Final Report - Plan 1", Prepared for CANMET and Ruttan Operations of Sherritt Gordon Mines Limited by Falcanbridge Limited, Sudbury Operations, CANMET Project No: 4-9147-2, July 1985.

2. S. Vongpaisal et. al. — "Communication System for Isolated Areas in Mines", 88th Annual General Meeting of CIM, Montreal, Canada, May 1986.

3. S. Soneff & S. Vongpaisal — "Communications Systems for Isolated Areas in Mines Phase II", 89th Annual General Meeting of CIM, Toronto, Canada, May 1987.

APPENDIX A

ROCK MECHANICS MONITOR UNIT

WIRELESS ROCK MECHANICS DATA TRANSMISSION SYSTEM

Rock mechanics instrumentation sites are generally located in remote, inaccessible and often dangerous areas of mines. It is often undesirable for mine personnel to access such sites to monitor instruments such as shear strips, extensometers and vibrating wire stressmeters. In addition, recording measurements manually is both tedious and time-consuming, often requiring a full-time technician. For these reasons, may be desirable to have remotely monitored rock mechanics instrumentation, where data from several instrumentation sites is gathered centrally, preferably on surface, for subsequent analysis. Conventional hard-wired remote instrumentation is vulnerable to line damage, and the installation of cabling suitable for data transmission is expensive.

If a mine-wide radio communication system already exists, it can be utilized to transmit the remotely-recorded rock mechanics data, eliminating expensive wiring and the duplication of existing communications systems.

IMS Electronics has developed a Wireless Rock Mechanics Data Transmission System (RMDS) that is used in conjunction with the Montan-Forschung FM Voice Communications System. Monitored data is transmitted from a remote monitoring unit by radio to a base station, where it is then re-transmitted via twisted pair cable to a desktop computer.

Each RMDS unit can monitor up to 16 channels of analogue (voltage or current) and/or contact sensor inputs. Typical

applications are extensometers, shear strips, and warning devices, such as rock movement monitors. Work is underway to include frequency monitoring, such as vibrating wire strain gauges.

The RMDS is made up from the following (see attached diagram):

1. Sixteen channel input, differential analogue and/or contact sensor, multi-plexed to a 12-bit resolution analogue/digital converter.

2. Microprocessor. An 8-bit Motorola 6802 microprocessor translates each channel into a 16-bit (2 byte) digit. The readings are then combined to form a data gram.

   The format of the data gram is:

Byte #	1	2	3	4	5	. . .	34	35	36	37	38	39	40
	[]	[]	[]	[]	[]	. . .	[]	[]	[]	[]	[]	[]	[]
	preamble		RMD ID#	channel #1 data			channel #16 data		bit count	RMD ID#	Xor check sum		post-amble

   Three data grams are combined to form a complete telegram ready for transmission via a Universal Synchronous/Asynchronous Receiver/Transmitter (USART).

3. Modem. A Bell 103 compatible modem transmits the complete telegram at 300 baud.

4. RMDS Output. Data output is either via an on-demand serial port to a hand-held (local) computer or is transmitted over the Montan-Forschung radio communications system. Radio transmission is via the inbuilt antenna/transmitter.

5. Data Transmission. Data is transmitted as an FM signal at 430 kHz (the standard MF voice transmission frequency) to the MF base station. Data transmission can be heard on the voice system as a one-second burst of 1 kHz noise. A line driver at the base station amplifies the signal and sends it to surface via a twisted pair cable. The line driver incorporates both gain and signal limit controls.

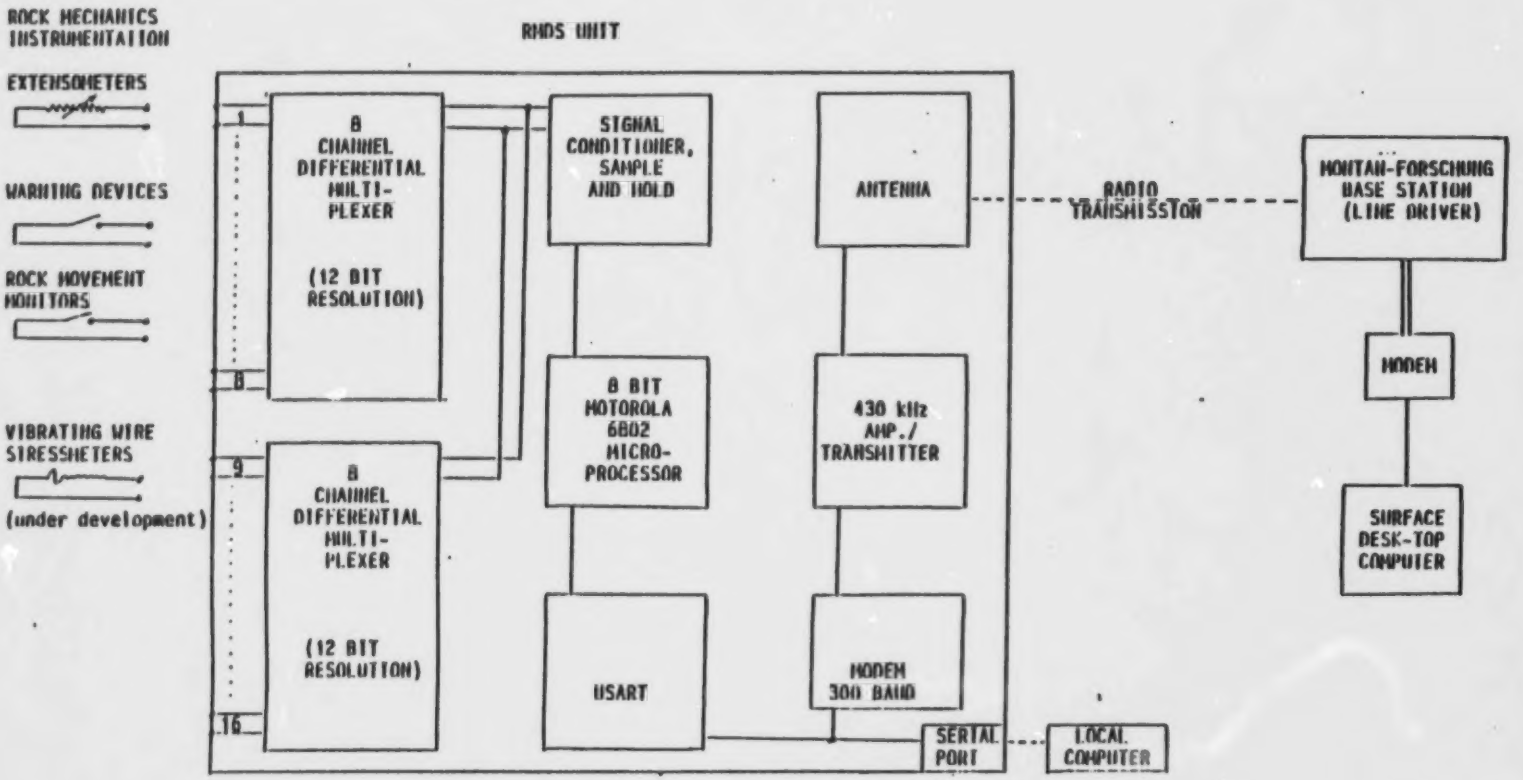
6. Data Recording. Data is received, via a modem, by a surface computer which stores, prints, and/or plots the measured data as required.

The frequency of monitoring is set at the RMDS unit using internal switches and can be varied from once every 20 seconds to once every four days. The unit identification number is also set internally, from 1 - 256.

Except when powering measurement devices and transmitting data, only a low power clock (0.1 microamp) drains power from the internal lithium batteries. Battery life is expected to be approximately ten years at ten readings per day.

At Ruttan Mine, the Rock Mechanics Data Transmission System is monitoring a standard rod extensometer installed at 730 mL in stope 27J. The extensometer head requires a 12 volt unregulated power supply, which is applied by the RMDS unit, to activate rotary potentiometers which supply an output of 10 mV per mm movement. On surface, a Radio Shack TSR80, which has a built-in modem, will be used to monitor and print the monitored data.

WIRELESS ROCK MECHANICS DATA TRANSMISSION SYSTEM



ROCK MECHANICS SOFTWARE DESCRIPTION

The data gram will be the packaged data transmitted by the radio system. This package will contain a preamble, RMD ID number, 16 words of analogue data, a bit count byte, the RMD ID number again, an exclusive or'd check sum byte, and finally a post-amble.

The format of the serial data will be 1200 baud 8 bit ASCII with even parity and 1 stop bit. The package will be 40 bytes long and will be transmitted three times in succession (i.e. 3 x 40 = 120 bytes). At 1200 baud and 10 bits/byte this will take one second to transmit.

The format of the data gram will be:

Byte #	1	2	3	4	5	. . .	34	35	36	37	38	39	40
	[]	[]	[]	[]	[]	. . .	[]	[]	[]	[]	[]	[]	[]
	preamble		RMD ID#	channel data			channel #16 data		bit count	RMD ID#	Xor check sum		post-amble

Where:

Byte #	Name	Description
1 & 2	Preamble data	This is a header to check all serial data bits are valid and to acknowledge a start of the data gram. The two bytes will be byte 1 01010101 & byte 10101010.
3	RMD ID#	This is the rock mechanics device id # which will be used to identify who is sending the data. This will be an 8 bit byte with a possible range of 0 to 255. This id is set on one of the Dip switches on the RMD board.
4 & 5 . . . 34 & 36	Channel #1 data	The analogue data is stored in this slot with 2 bytes (16 bits) per channel. Sixteen channels (32 bytes) will be located in this section of the data gram. The format of the 2 byte channel data is Byte #3 4 DDDD DDDD DDDD XXXO MSB LSB

Where:

D is a Data bit (1 or 0). The A to D converter is a 12 bit device.

X is a Data bit or zero depending on the gain setting (G_0 & G_1). The gain is programmed on the HI-9590 address A4 & A5.

O is always zero.

This number will correspond to a full range of ± 5 Volts or ± 10 Volts depending on the A/D setting (Hardware selectable).

e.g.

Data	± 5 Volt Range	± 10 Volt Range
0000 0000 0000 0000	-5 Volts	-10 Volts
0111 1111 1111 1110	0 Volts	0 Volts
1111 1111 1111 1110	+5 Volts	+10 Volts

36	Bit count	The bit count is an error check byte which contains the total number of 1 bits in the channel data bytes (byte 4 to 35) excluding parity. This number can range from 0 to 192 (i.e., 12 bits x 16).
37	RMD ID#	As previously defined. This is just an extra check to identify the data package.
38	Xor Check Sum	The exclusive or check sum is used in an error check byte of the data from byte 3 to byte 37. Each byte is exclusive or'd to one another and the resultant is stored in byte 38.
39 & 40	Post-Amble Data	This is a trailer to check that the complete data gram was transmitted correctly. The data which is contained in these two bytes are byte 39: 0011 0011 and byte 40: 1100 1100.

ROCK MECHANICS MEMORY LOCATION

Memory Location	Access	Description
0000 - 0027	R/W	Data gram temporary storage area, located on internal 6802 RAM.
0028 - 003F	R/W	Work area scratch pad, located on internal 6802 RAM.
0040 - 007F	R/W	Stack 64 bytes, 8 entries, located on internal 6802 RAM.
0800	R	Rock Mechanic device ID number (0 to 255) from dip switch setting.
1000 - 103F	W	Multiplexer channel number and gain setting. The channel number is 0 to F and the gain setting is 1000, 1010, 1020, 1030 which is added to the channel number. The gain setting/address correspondence is: 1000 +1 1010 +2 1020 +4 1030 +8 e.g. 101E is channel 15, gain setting +2.
1800	R/W	A/D converter. A write-to-address 1800 starts a 12 bit A-to-D conversion. A read-to-address 1800 reads the 8 MSB of the 12 bit conversion. This should be done at >25 nseconds after the conversion was started.
1801	R	A read at this address will read the remainder 4 bits (LSB) and 4 zeroes. The read can be done immediately after the 1800 (8 bit) read.
2000	R/W	The USART status read and control write address. A read to this address will give the status word which is:

Bit 0 receive data register full
1 transmit data register empty (high empty)
2 data carrier detect
3 clear to send
4 framing error
5 receiver overrun
6 parity error
7 interrupt request

if Bit 1 is high, data can be transmitted to the USART; if low, the USART is busy. Writing to this address will set the control word for the USART.
The control bits are:

CR6	CR5	CR4	CR3	CR2	CR1	CR0	
					1	0	clock divide by 64
					1	1	master reset
		1	1	0			8 bit, even parity, 1 stop
0	1						RTS=low, transmit interrupt enabled.

2001 W Write data to the USART transmission buffer. A control read on address 2000 with bit 1 being low is required to check that the USART transmit buffer is empty before a write can be done.

2002 R Read the 6 dip switch setting to set up the USART control word. The switch settings and the functions required are:

Switch							Control Register							Description
7	6	5	4	3	2	1	0	6	5	4	3	2	1	0	
					0	1		x	x	x	1	0			600 Baud
					1	0		x	x	x	1	0			1200 Baud
			0	0	0			1	0	1	x	x			8 bit, 1 stop bit
			0	0	1			1	0	0	x	x			8 bit, 2 stop bit
			0	1	0			1	1	0	x	x			8 bit, 1 stop, even parity
			1	1	0			1	1	1	x	x			8 bit, 1 stop, odd parity
x	x	x													

2800 R Reading this address will shut off the power to the microprocessor. This address is only used to shut down the operation cycle. The timer clock continues to run and will power up the device at the next sampling cycle.

Bit 0 receive data register full
1 transmit data register empty (high empty)
2 data carrier detect
3 clear to send
4 framing error
5 receiver overrun
6 parity error
7 interrupt request

if Bit 1 is high, data can be transmitted to the USART; if low, the USART is busy. Writing to this address will set the control word for the USART.
The control bits are:

CR6	CR5	CR4	CR3	CR2	CR1	CR0	
					1	0	clock divide by 64
					1	1	master reset
		1	1	0			8 bit, even parity, 1 stop
0	1						RTS=low, transmit interrupt enabled.

2001 W Write data to the USART transmission buffer. A control read on address 2000 with bit 1 being low is required to check that the USART transmit buffer is empty before a write can be done.

2002 -- - - - - R Read the 6 dip switch setting to set up the USART control word. The switch settings and the functions required are:

Switch							Control Register							Description
7	6	5	4	3	2	1	0	6	5	4	3	2	1	0	
					0	1		x	x	x	1	0			600 Baud
					1	0		x	x	x	1	0			1200 Baud
		0	0	0				1	0	1	x	x			8 bit, 1 stop bit
		0	0	1				1	0	0	x	x			8 bit, 2 stop bit
		0	1	0				1	1	0	x	x			8 bit, 1 stop, even parity
		1	1	0				1	1	1	x	x			8 bit, 1 stop, odd parity
x	x	x													

2800 R Reading this address will shut off the power to the microprocessor. This address is only used to shut down the operation cycle. The timer clock continues to run and will power up the device at the next sampling cycle.

ROCK MECHANICS SOFTWARE PROGRAM DESCRIPTION

The microprocessor used in the rock mechanics monitor is a Motorola 6802 which contains an internal 128 bytes of RAM. The program will be stored in a 2716 EPROM (2 K bytes) at location F800. The program itself will start at address F800 and can continue in memory up to the interrupt vector table at location FFF8 to FFFF. A description of the program follows.

A. The microprocessor is powered up and the reset line comes up in about 10 milliseconds.
The reset interrupt vector goes to location "FFFE, FFFF" and picks up the starting location of the program "F800".

B. The program at location "F800" clears out RAM address "0000 to 007F" and then sits in an idle loop for 10 milliseconds to wait for the Analogue electronics to stabilize.

C. The preamble and post-amble words are stored into the data gram location in RAM memory (4 bytes total).

D. The rock mechanics device ID is read from the dip switches and stored in the data gram in two locations (2 bytes).

E. The USART is given a master reset (control register CR0, CR1) and then the USART status dip switches are read (Switch 2 to 4). The USART is then prepared to transmit at a divide by 64 ratio and in a format defined by the switch settings.

F. The 16 channels of analogue data are read and stored into the data gram. Each channel is read up to 4 times at the different gain settings and the maximum gain is used to read the analogue signal.
The algorithm to read the data channel is:

```
DO Channel = 1 to 16.
     Set gain to 1
     DO WHILE MSB is not negative or gain setting <=8
          set up gain and channel address G1G0CH3CH2CH1CH0
          WRITE gain and channel address to multiplexer
          WRITE to A-to-D convertor to start converting
          cycle (Address "1800")
          wait 30 nsec
          READ 8 MSB from convertor "1800"
          READ 4 LSB from convertor "1801"
          check of negative MSB and EXIT if negative or gain
          setting is equal to 8
          INCREMENT gain setting (1,2,4,8)
     END WHILE
     SHIFT data by 0,1,2,3 (i.e., 1,2,4,8) to correct for
     gain settings (SRL)
     STORE the data word in the appropriate channel data
     slot in the data gram.
NEXT Channel
```

G. Count the number of 1 bits in the channel data (all 16 words) and store in the data gram bit count. The number should range from 0 to 192.

H. Exclusive OR the device ID#'s, channel data, bit count and device ID# again and store in the data gram Xor position.

I. Now transmit 3 data grams out the serial port (USART) to the radio link.

```
DO Data gram = 1 to 3
     DO Character = 1 to 40
          CHECK STATUS of transmission buffer.  If full,
          loop for 10,000 times and EXIT if not empty (bit 1
          of Address "2000")
          WRITE a character to USART "2001"
     NEXT Character
NEXT Data gram
```

J. The data have been sent now turn the power off to the microprocessor, A-to-D and radio transmitter by a READ to address "2800".

R.S.T.™
INSTRUMENTS LTD.

ROD EXTENSOMETER

A low cost, convenient instrument for the monitoring of ground displacements. Designed to withstand severe field conditions and accommodate transverse shear. The unit is supplied completely assembled and sealed for grouting into the borehole. Rod displacement readings may be taken manually using a dial gauge or monitored continously with a remote readout head.

CONSTRUCTION:

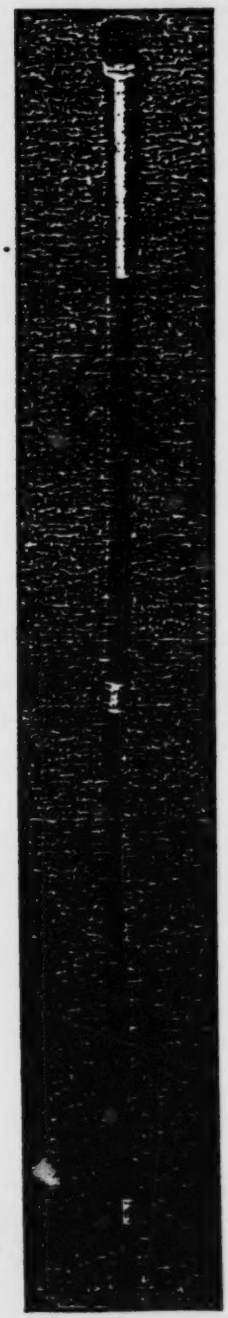
The extensometer consists of a maximum of 7 oiled spring steel rods, each sheathed in a neat fitting plastic tube. One end of each rod is connected to a ribbed steel anchor, grouted into the borehole. The other end is fitted with a brass cap which is the displacement surface with reference to the stainless steel collar tube. The sheathed rods are assembled around a compressible filler and spirally bound for rigidity. The whole assembly is finally sheathed in a polyethylene tube, sealed at each anchor point. This construction provides a void for limited transverse shearing of the borehole without the rods being jammed. Before coiling of the extensometer, the ends of the rods are locked in position at the collar and are released only after the grout has hardened in the borehole.

INSTALLATION:

The extensometer is supplied fully assembled in a 1.2 metre diameter coil. At the installation site, the unit is uncoiled, fitted with suitable grout and airbleed tubes, and installed into the borehole. After grout has been injected and initial set has been reached, the protective cap is removed, the rods released, and the initial displacement recorded. All collar components are of brass or stainless steel and each rod is clearly identified.

ADVANTAGES:

- Accurate at low cost,
- Rod length is virtually unlimited,
- Unit is supplied completely assembled and sealed, ready for installation,
- Assembly is light in weight and easily handled, installation is quick and simple,
- Compact design allows installation in boreholes of minimum size; up to 7 rods may be accommodated in a 60mm borehole,
- Limited transverse shear accommodated, without jamming of rods,
- Readily converted to remote readout at anytime after installation.
- The electrical head does not require a specialized readout instrument - only a power supply and digital multimeter.



FOUR CHANNEL REMOTE HEAD
WITH MANUAL OVER-RIDE ASSEMBLY

SPECIFICATIONS:

Range	—	150mm (300 mm optional)
Input	—	5-24 VDC
Output	—	0-2.5 VDC
Resolution	—	0.1mm standard 0.01 optional
Channels	—	7 maximum

REMOTE READOUT HEAD:

A compact head assembly which permits all rods in an extensometer installation to be monitored continuously from a distant readout station.

SYSTEM:

Each rod drives a rotary potentiometer through a precision rack and pinion. A movement of 150mm (300mm optional) can be monitored by the linear change in voltage. The voltage output readout head has a voltage regulator and individual bridge type circuits for each sensor, enabling the readout station to be quite a distance from the extensometer heads without loss of resolution.

The heads are manufactured from brass, PVC, and stainless steel, and are completely sealed against the ingress of moisture.

The heads can be factory installed or attached to the collar in the field at any time after installation of the extensometer rod assembly.

An optional manual over-ride allows manual readings in addition to electrical readings.

The output of the head can be monitored using a simple digital multimeter or recorded on a data logger.

ORDERING INFORMATION:

- Advise if manual over-ride is required.
- Nominate number of sensors required.
- Specify if optional resistance output is required.
- Advise length of cable required and plug types etc.
- Advise if 150 mm or 300 mm range.

READOUT UNITS

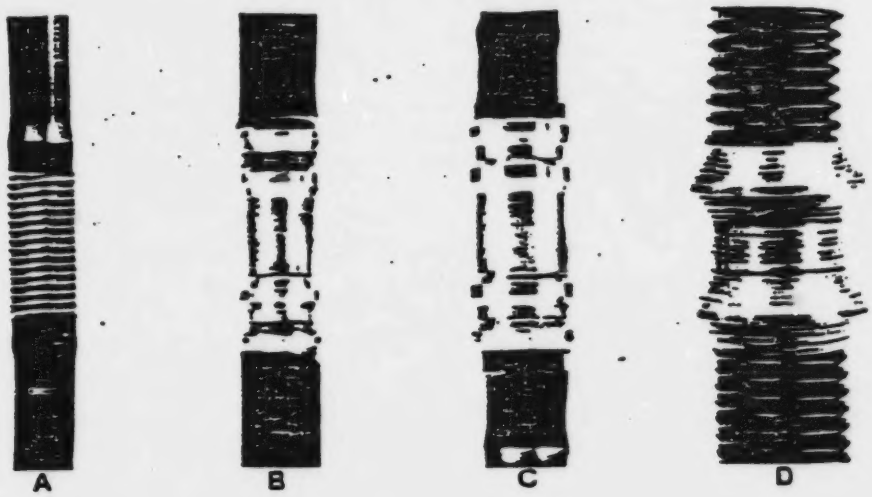
Voltage output, remote readout extensometers can be monitored with any high accuracy, digital multimeter, using an external DC power supply.

A display unit is available with these features:

- Digital display, reading directly in mm (to 0.1mm).
- Heavy duty, rechargeable battery for continuous monitoring in excess of 8 hours.
- Selector switch for up to 7 channels.
- Heavy duty sealed case with lockable lid.
- Junction box facilities for multiple sensor installations on special order.

TECHNICAL DETAILS:

ROD ASSEMBLIES:



					RECOMMENDED			
Rod assembly type	A		B		C		D	
Anchor diam.(mm)	25		33		41		65	
Details	Nominal Borehole diam.(mm)	Maximum Number of Rods	Nominal Borehole diam.(mm)	Maximum Number of Rods	Nominal Borehole diam.(mm)	Maximum Number of Rods	Nominal Borehole diam.(mm)	Maximum Number of Rods
UPHOLE With external air bleed tube 10mm I.D.	45	4	51	5	60	7	85	7*
DOWNHOLE With external grout tube 15mm I.D. **	51	4	57	5	65	7	90	7*
UPHOLE With internal air bleed tube 10mm I.D. ***	32	3	38	3	45	5	75	7
DOWNHOLE With internal grout tube 10mm I.D. ****	N/A	N/A	38	3	45	5	75	7

Notes:

* Up to 19 rods can be used with special collar assembly (shear accommodation is substantially reduced).

** Use 20mm grout tube if possible, particularly for extensometers longer than 30 metres.

*** Type A. assembly has airbleed tube 4.5mm I.D. only, not recommended for extensometers longer than 15 metres.

**** Not recommended for extensometers longer than 20 metres.

TECHNICAL DETAILS (CONTINUED)

COLLAR ASSEMBLY

The stainless steel collar assembly has four features:

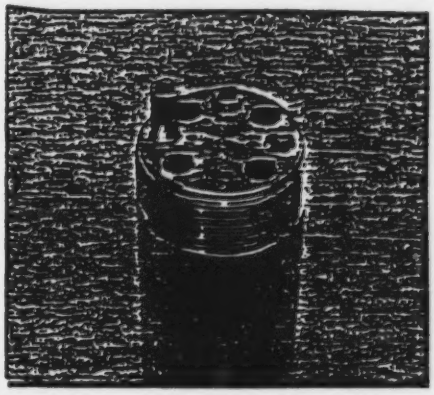
(1) A machined reference surface, protected by a heavy PVC cap.

(2) The rod guide tubes and outer sheath are securely anchored in epoxy resin.

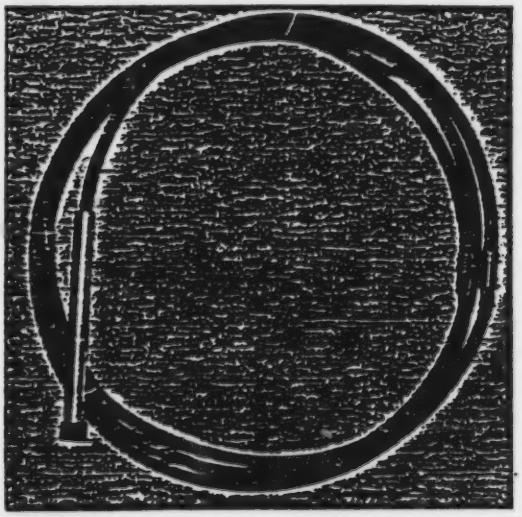
(3) A remote readout head can be fitted to any installed extensometer by removing the cap and making a simple threaded connection to each rod.

(4) Rods individually sheathed in brass guide tubes.

Collar assembly dimensions are 550 x 48mm diameter. The borehole should be reamed to 75mm diameter x 700mm deep to accommodate the collar assembly plus grout and air bleed tubes.



MANUAL COLLAR ASSEMBLY



MANUAL EXTENSOMETER AS SHIPPED

ORDERING INFORMATION:

- Nominate number of rods and length of each from the collar.
- Specify range required when in excess of 150mm.
- Specify anchor type.
- Confirm if grout and air bleed tubes are to be fitted to extensometers or supplied separately.
- Specify range of axial displacement to be accommodated.
- Advise if dial gauge is required.
- Indicate if excessive transverse shear is likely or expected.
- Advise if manual or electrical head.

GROUND CONTROL (Sudbury) LTD.
1150 Kelly Lake Road, Sudbury Ont. P3E 5P4
Telephone (705) 673-3020 · Telex 067-7538

Represented by:

Manufactured under exclusive licence for Geosystems, Australia, by:

R.S. TECHNICAL INSTRUMENTS LTD.
No. 18 - 1780 McLean Avenue,
Port Coquitlam, B.C. Canada V3C 4K9
Telephone (604) 941-9155 / 941-4848

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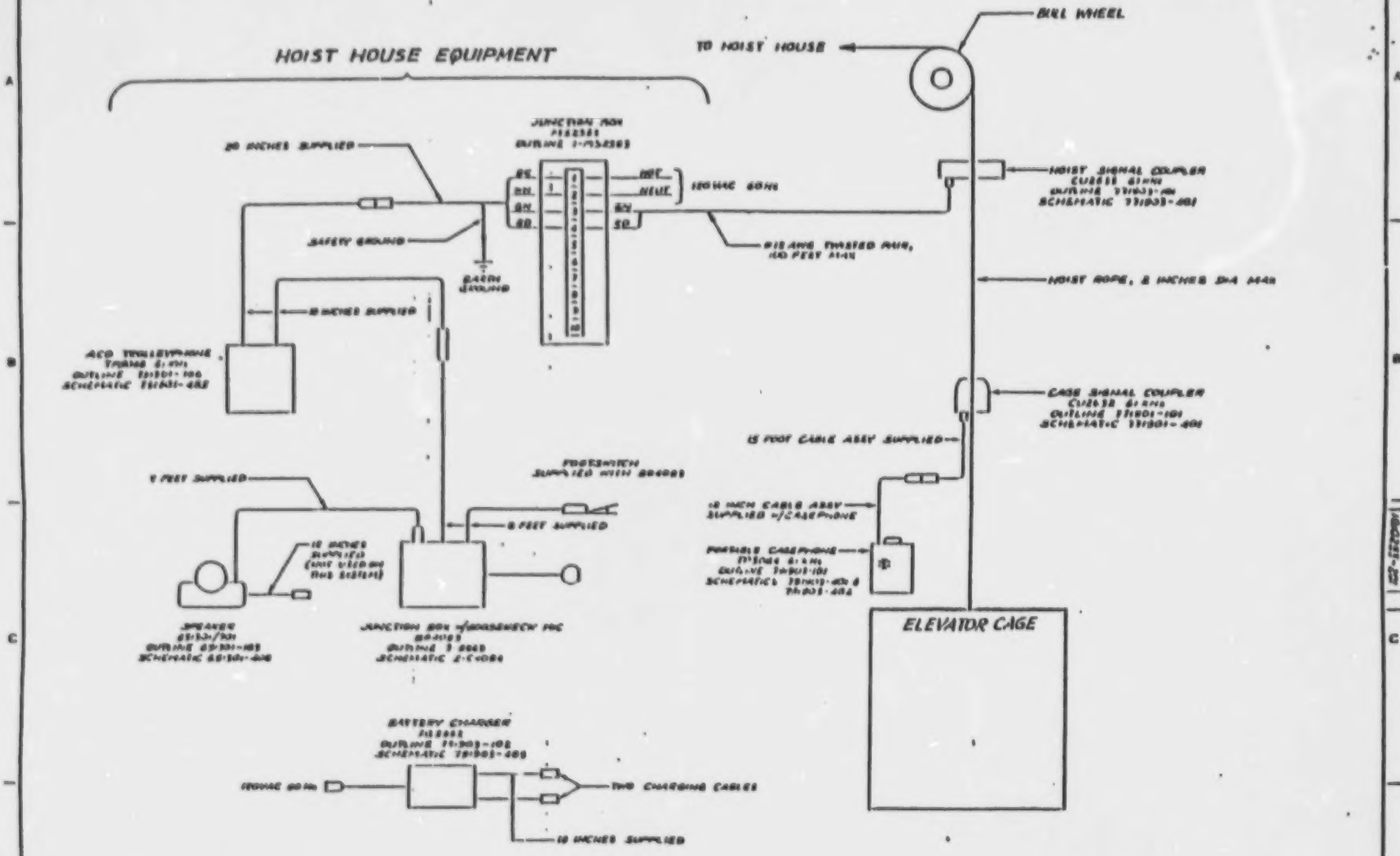
APPENDIX B

HOIST RADIO SYSTEM



TYPICAL CAGE COMMUNICATION SYSTEM
NATIONAL MINE SERVICE COMPANY
PITTSBURGH, PENNA.

gulton
Power Division
Gulton Industries, Inc.

1810253-201

GENERAL DESCRIPTION

INTRODUCTION

The Femco Portable Cagephone, TP5084, is a self-contained frequency modulated RF carrier transceiver, except for an external antenna. The stainless steel case protects the internal components from most hazards encountered in this application. Three toggle switches control the operation of the cagephone. They are: 1, UP-TO-TALK which keys the transmitter in this manual-simplex communications system; 2, the BELLING switch keys the transmitter and an internal tone oscillator to signal the hoist operator; and 3, the ON-OFF switch. The unit is powered by an internal 4.5 amp-hour battery.

SPECIFICATIONS

The electrical, mechanical and environmental specifications for the unit are as follows:

ELECTRICAL:

GENERAL

DC Supply Voltage	10.5 VDC to 15 VDC (12 VDC nominal).
DC Supply Current	Transmit-4.0 amperes Standby-0.1 amperes
Frequency Range	61 kHz
Channels	61 kHz
Insulation	Unit isolated from ground. Able to withstand a 2500 VDC High Potential Test.
Operating Range	80 dB.

TRANSMITTER

RF Output Power	13 volts into 25 ohms @13 VDC supply.
RF Load Impedance	5 ohms to 200 ohms, (25 ohms nominal).
Frequency Stability	Not more than $\pm$0.5 kHz drift throughout the specified voltage and temperature ranges.
Frequency Deviation	+3% of channel frequency below 100 kHz $\pm$ 3 kHz above.

RECEIVER

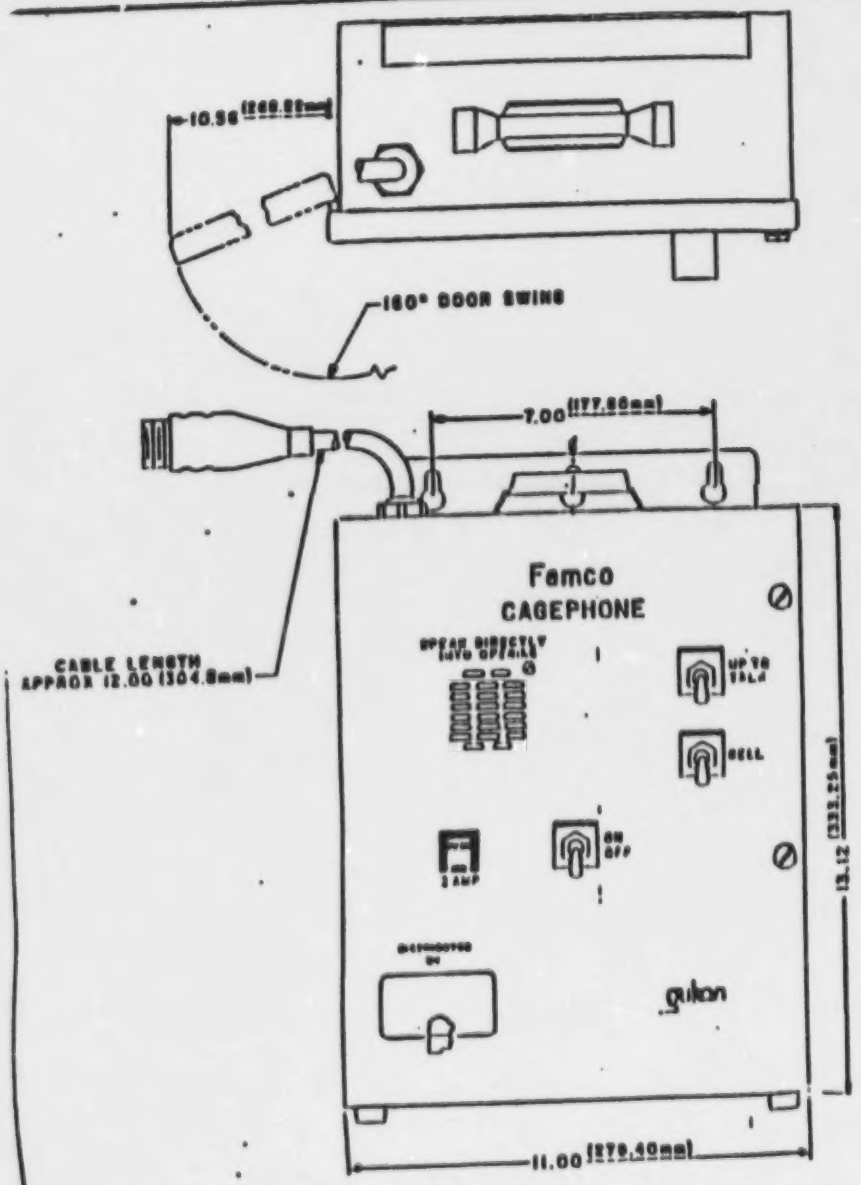
RF Input Impedance	100 ohms @ channel frequency.
Audio Output Power	6 watts into 16 ohm load.
Sensitivity	3 millivolts. Adjustable to 30 dB.
Selectivity	3 dB down @ ±4% below 100 kHz ± 4 kHz above.
	20 dB down @ ±10% below 100 kHz ±10 kHz above.
Squelch	Automatic balancing signal to noise type.

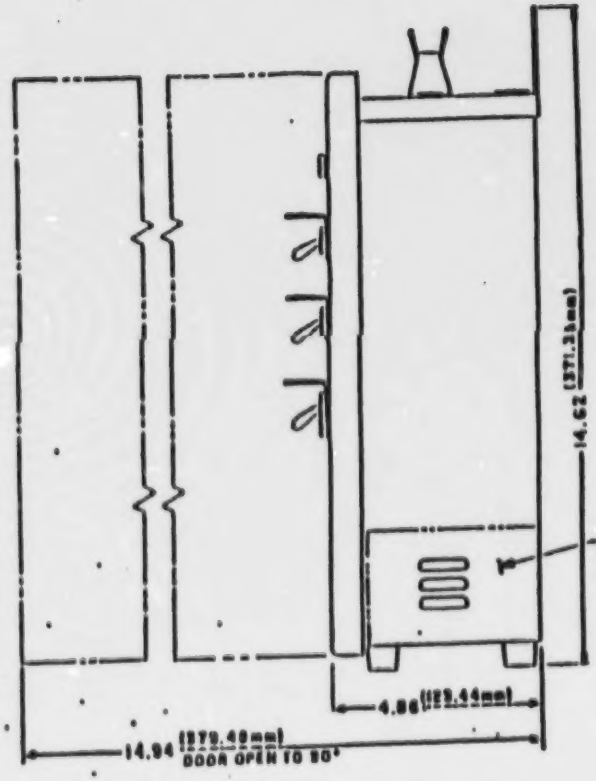
MECHANICAL:

Dimensions	4 7/8 " depth x 11" width x 14 5/8" height.
Weight	pounds
Construction	Stainless Steel.
Connections	All connections are moisture proof.
	Power and Signal - 4 contact male.

ENVIRONMENTAL:

Sealing	The electronics compartment is dust tight and moisture resistant. The battery compartment is ventilated.
Vibration	Exceeds EIA standards.
Temperature Range	-40°F to +60°C.





OUTLINE– STAINLESS STEEL PORTABLE CAGEPHONE W/. TALKBACK SPEAKER

gulton Famco Division

791903-101 A

791903-02
JULY 1980

WARNING - THE CONNECTOR SHELL OF THE POWER CONNECTOR MUST BE GROUNDED TO FRAME OR A GOOD EARTH GROUND TO PREVENT ELECTRICAL SHOCK IN THE EVENT OF A POWER FAULT IN THE CONNECTOR.

INSTALLATION

Refer to Figure 1-1. This figure shows the outline drawing of the Mine ACO Trolleyphone. Normally, the mounting bars (MO4153), provided with the unit, are wleded in place to a wall support or other similar structure. By removing the nuts from the shock mounts holding theunit to mounting bars the Trolleyphone may be removed for servicing.

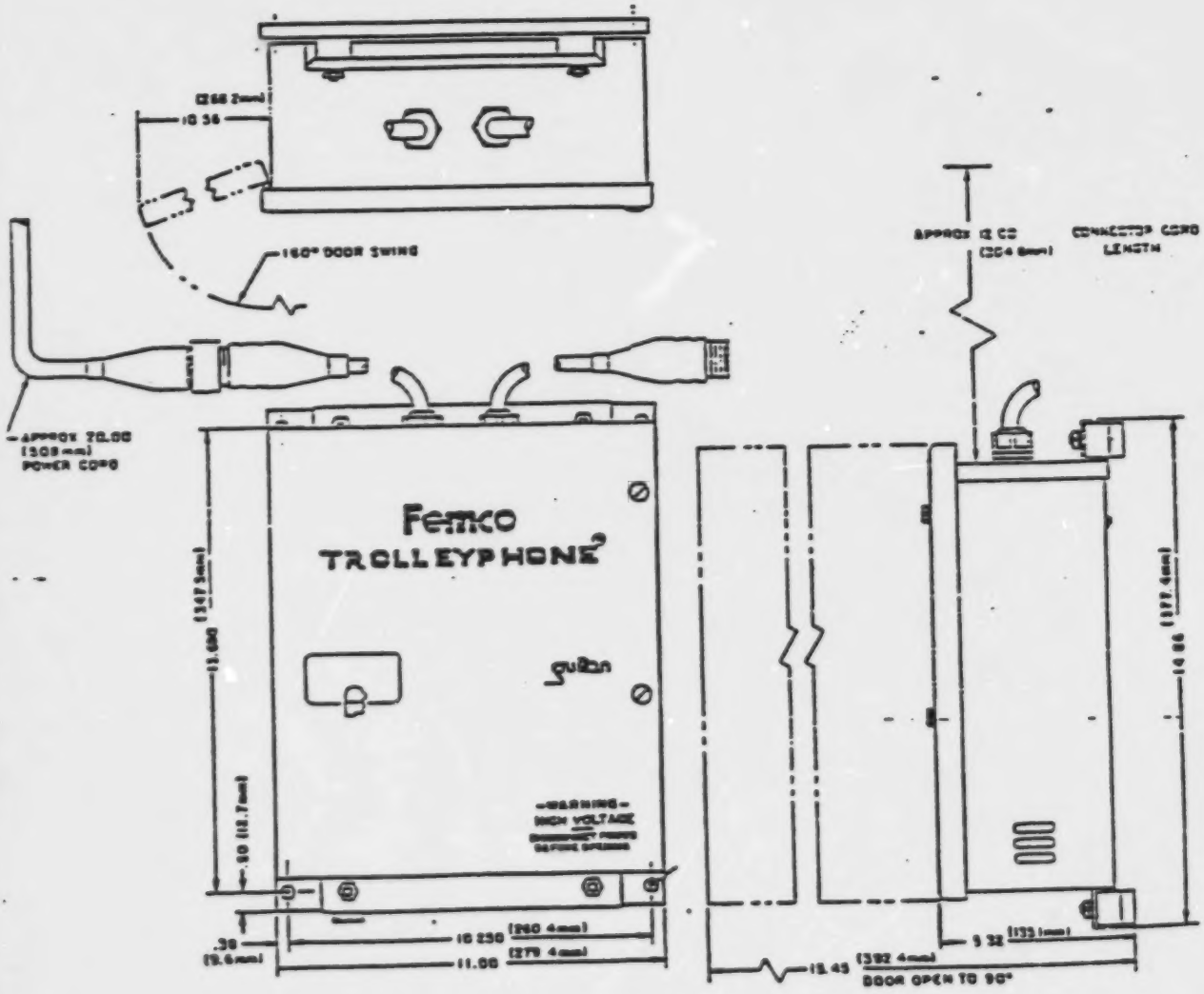
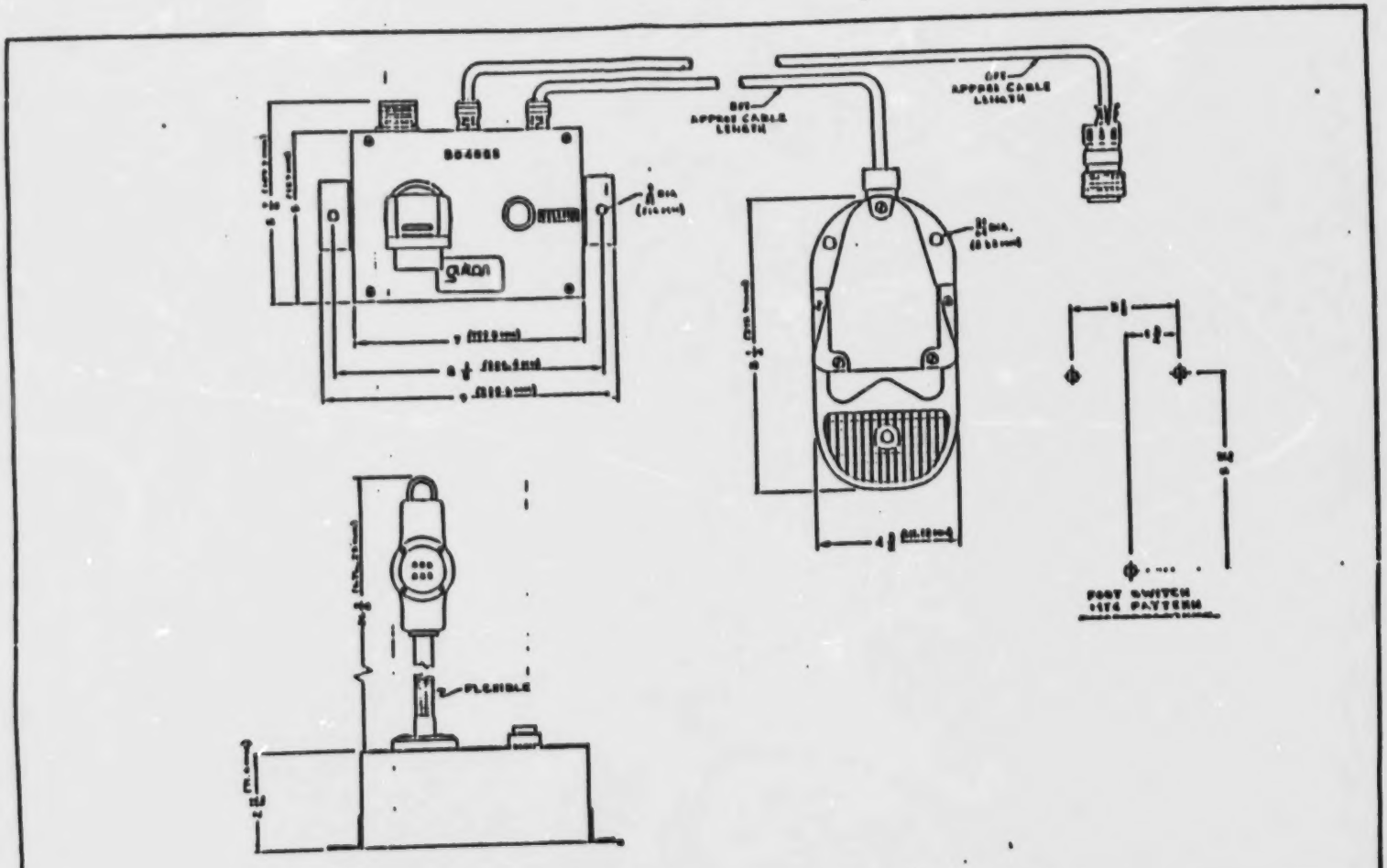


FIGURE 1-1 Outline Drawing of Mine ACO Trolleyphone



SCHEMATIC ____ S-C4884
ASSEMBLY ____ S-8868

OUTLINE_ GOOSENECK MIC W/
BELLING & FOOT SWITCH

KEMCO DIVISION
Gulton Industries, Inc.
3-8869

Figure 1-2 shows the 25 watt speaker that is a component part of some models. The speaker mounting bracket, which is also normally welded in place, may also be bolted. The speaker should be mounted as close as possible to the operator and directed toward his position. The speaker should also be located so as to protect the cable connectors from damage. Speaker volume is controlled by a knob on the front of the speaker.

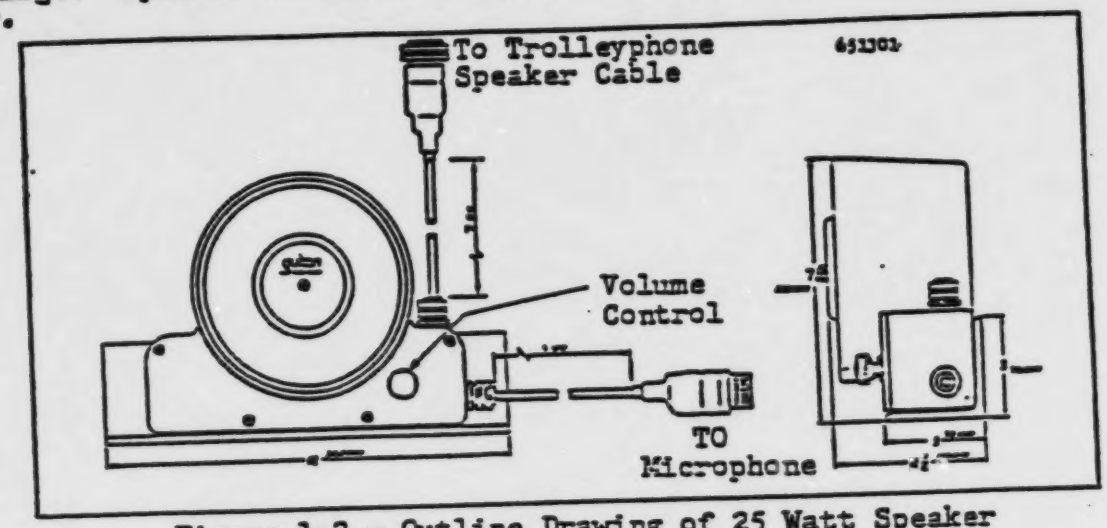
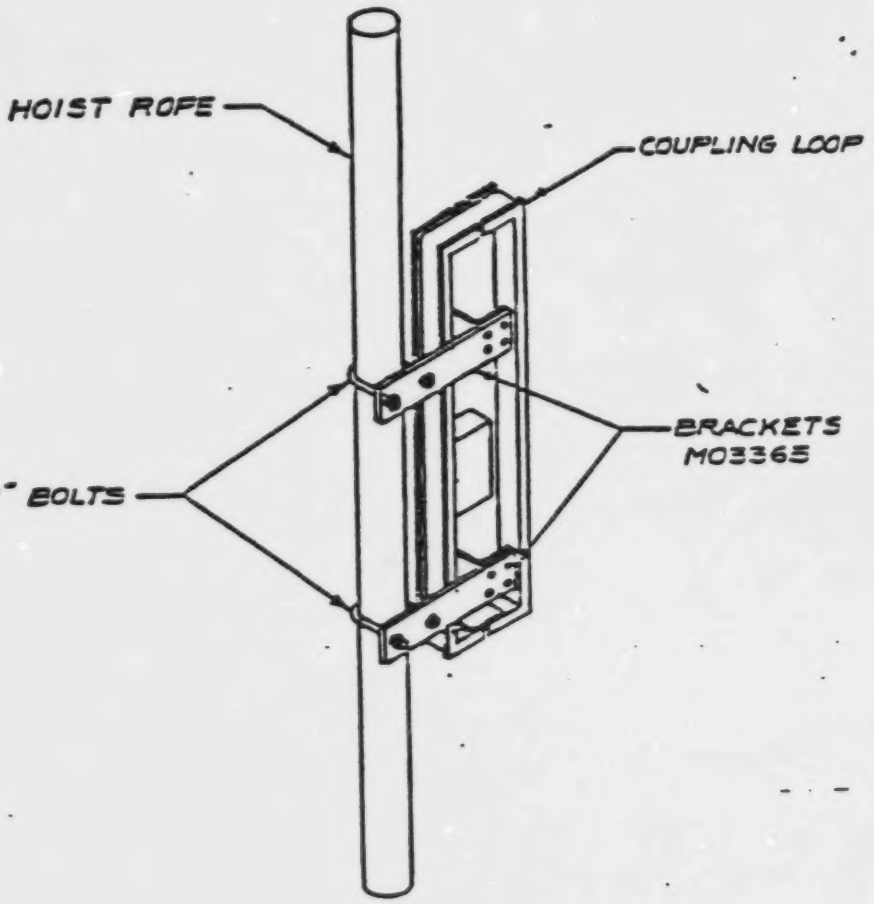


Figure 1-2 - Outline Drawing of 25 Watt Speaker

REVISIONS



INSTALLATION DRAWING
SIGNAL COUPLING COIL TO HOIST ROPE

DFTSMN. DFHENSLER 1-13-65
CHKD.
ENG. DEH 1-13-65

GEN. DWG. 2-7564
PART NO.
APPD. PW 1-13-65

1-7594

FENCO
IRWIN, PA

CONTRACT REPORT NUMBER OSQ84-00353
CONTRACTOR: HUDSON BAY MINING AND SMELTING
REQUISITION NUMBER 23440-4-9147-2

RESEARCH & DEVELOPMENT IN MANITOBA MINES
COMMUNICATION SYSTEM FOR ISOLATED AREAS IN MINES
FINAL REPORT - PHASE 1

Prepared for:

CANADA CENTRE FOR MINERALS AND ENERGY TECHNOLOGY
(CANMET)

and

RUTTAN OPERATIONS OF SHERRITT GORDON MINES LIMITED

by

FALCONBRIDGE LIMITED, SUDBURY OPERATIONS

CANMET Project No.: 4-9147-2 July 1985

100 pp

MICROMEDIA

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Work on the project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada under the Canada/Manitoba Mineral Development Agreement.

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DSS Contract Serial No.: OSQ84-00353
CANMET Project No.: 4-9147-2
CANMET Scientific Authority: Dr. S. Vongpaisal

July 1985

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ABSTRACT

This report reviews the state-of-the-art of communication technology, both data and vocal, for underground mines with the main objective of recommending the best available system for pilot testing in a Canadian Mine. The emphasis is on mine-wide radio vocal communication.

In the process of this study, many mines and research organizations in a number of countries were visited. These visits along with an extensive literature search enabled the completion of the following tasks: observe and analyze the commercially available systems; obtain general opinions regarding the trend in new developments; compile actual benefits realized; define parameters contributing to the success of an installation; and, finally, decide upon the best system available.

The result of this study indicates that the frequency modulated medium frequency system offers the best potential for mine-wide vocal communication at present. The medium frequency system can also be used for mobile equipment monitoring and control.

Ce rapport presente une analyse des methodes de communications utilisees dans les mines et a pour objectif principal la selection d'un systeme de communications verbales couvrant la mine entiere pour une installation pilote dans une mine Canadienne.

Au cours de ces travaux, les auteurs ont visite un nombre important de mines et de laboratoires de recherche parmis les plus modernes au Canada et a l'etranger. Grace a ces visites, une etude poussee des differents systemes disponibles a pu etre completee, faisant valoir leurs avantages et leurs inconvenients ainsi que l'identification des criteres de selection tels que definis par les techniciens et les operateurs des mines. De plus, on donne un apercu des systemes a venir.

Cette etude conclue que les systemes a modulations de frequence dans la gamme de 300 KHz a 3,000 KHz offrent les plus grands avantages en ce qui concerne les mines souterraines a plusieurs niveaux, pouvant meme inclure parmis leurs fonctions, l'acquisition de donnees.

FOREWORD

This report was prepared under Contract DSS14SQ.23440-4-9147-2 between the Department of Supply and Services, Government of Canada and Ruttan Operations, Sherritt Gordon Mines Limited. The study was carried out by Falconbridge Limited's Sudbury Operations as subcontractor to Ruttan Operations. Dr. S. Vongpaisal of the Canada Centre for Mineral and Energy Technology (CANMET) acted as scientific authority on the project.

All work on the project was performed at Sudbury Operations under the general supervision of Falconbridge Management. The following personnel are principal contributors:

Y. L. Su	-	Senior Operations Research Engineer
L. C. Gregg	-	Chief Instrumentation Engineer
J. L. Fuchs	-	Senior Mine Technology Engineer
J. A. St. Pierre	-	Electrical Engineering Supervisor

Sincere thanks are extended to Dr. S. Vongpaisal and to Mr. P. J. M. Hooper, Manager, Mr. N. Agar, Plant Services Superintendent, Mr. S. Soneff, Electrical Engineer of Ruttan Operations, for their cooperation and continuous assistance on all aspects of this study. The encouragement and assistance of Falconbridge management and other company personnel are acknowledged, as well as the personnel at the mines and research agencies visited in Canada and abroad.

1. SUMMARY

1.1 Introduction

Mine-wide vocal communication has been identified by mine operators and mining authorities as one of the most promising technologies to improve worker safety and increase over-all mine productivity. Unfortunately, it is not unusual for a mine operator considering an installation to find it difficult to identify the best available system. Some operators who installed a system on a trial basis found it doomed to disuse after initial success was achieved. In 1984 the Ontario Mining Association surveyed its members to review the research completed or in progress on mine communication systems and listed seventeen radio systems as available, with some others shown promising. Other sources, especially those abroad, strongly suggested that underground radio communication is a mature technology, that existing hardware is regarded as standard mining equipment and that radio communication is an integral part of daily mining operations.

In the area of data communication, a different situation exists. A wealth of hardware systems is available on the market and most installations appear to be successful, technically and economically. Nevertheless, applications are in the infancy stage. Many mine operations are unaware of the existence and potential of this technology, and many mining operations which could benefit from such technology remain to be explored.

The purpose of this study is to review the state-of-the-art of these technologies and to identify major factors contributing to the success of an installation.

Actual benefits generated by various installations are identified. It is hoped that these examples will be helpful to mine operators in preparing their economic justification.

1.2 Mine-Wide Vocal Communication

Hardwired systems have been used for mine communication since the invention of the telephone. These systems have been continuously improved using up-to-date technology. At present many types of hardware are available and are acceptable communication methods for localized areas in the mine. For mine-wide communication, hardwired systems are too expensive and unreliable. Radio systems are more practical.

Underground radio communication has its unique features and difficulties which have prevented direct transfer of surface technology to underground applications. The complex geological structure, dielectric properties and conductivity of the rock, the dimensions and geometry of mine openings and environmental conditions are major factors to be considered when designing an underground system. These difficulties have generally been overcome through years of intensive effort by research organizations around the world. At present a number of systems is available commercially.

Systems that operate on the UHF band, 300 MHz to 3,000 MHz, provide fairly long distance (500 metres or longer) line-of-sight communication. For example, an 800 MHz system has recently been developed by Motorola Inc. and is commercially available. With the aid of passive reflectors, signals can be guided to overcome the line-of-sight limitation. A mine-wide communication system using this principle with distributed antennae and two-way signal boosters has been proven technically feasible.

The VHF radio wave, 30 MHz to 300 MHz, does not propagate as well as UHF in open air underground but, when coupled into a transmission line, long-distance and wide-area communication can be achieved. The most effective transmission lines at present are co-axial and leaky co-axial cables. With co-axial cable, antennae are required on the transmission line. IAL and Radiax are brands of these systems available commercially and a number of successful installations have been reported.

Both UHF and VHF signals suffer attenuation losses in the transmission line. Even with low-loss coaxial cable, signal amplification is required every few hundred metres and the transmission line has to serve as a power-carrying cable also. On the other hand, transceivers, both hand-held and vehicular units, are readily available from many manufacturers of surface radio communication systems. This may present a cost advantage.

Medium frequency (MF) systems, 300 KHz to 3 MHz, have captured attention in recent years. Radio signals in this band have been found to propagate through the earth. MF can be coupled very easily into existing mine cables, pipelines or simple wires and transmitted long distances without amplification.

Systems based on medium frequency are or soon will be available commercially from all over the world, typically the Silec system (France), the Nagano system (Japan), the Plessey system (Britian), the M.S.A. and the Stolar systems (U.S.A.) and the Montan Forschung system (West Germany). Most of these use amplitude modulation to imprint voice onto the radiowave because of simpler design. This suffers a high noise disadvantage especially around high voltage mining equipment. The trend is to the frequency modulated system. Stolar of U.S.A. have begun designing such a system while Montan Forschung of West Germany have had one on the market for several years.

The frequency modulated medium frequency system appears to be the best choice for mine-wide communication at present. Hardware and installation are simple. There is no need for expensive transmission lines or amplification. The need for communication specialists to design and install an MF system is not as critical as with transmission line systems and dead spots in the mine can be eliminated more easily.

1.3 Data Communication for Mine Monitoring

Data generated by sensors or from keypads must be transmitted to a receiving station for display, analysis and control. Depending on specific applications and the amount of data, transmission can be by radio, wire conductors and fibre optics.

Wire conductors are used mostly in monitoring stationary mining equipment and mine environment. Pumps, fans, conveyors, bins, electrical distribution etc. are monitored on a continuous basis by computer for the purpose of reducing manpower, shedding peak power and assisting in diagnosis of electrical or mechanical system problems.

Most present data communications techniques use "outstations" to accept and encode the data generated by sensors and to transmit the pooled signal along a common trunk line to the control centre. The common technique to encode signals from sensors for transmission is frequency shift key (FSK) encoding and the common technique to transmit data through a single line is time division multiplexing.

Commercially available systems for monitoring purposes are numerous. Generally complete packages including sensors, outstations, telemetry, computer and display units are provided. Special purpose sensors are manufactured by independent companies. At present each manufacturer has his own communication protocol which prohibits intermix of different makes. Common makes include Conspec, Gould-Modicon, Outokumpu, Transmitton, RFL, and Montan-Forschung.

Radio for data communication is used in remote control mining equipment and monitoring of mobile equipment. For monitoring, data is entered from keypad or from sensors and transmitted to the control centre. For remote control, data is entered through an operator's console and transmitted to the receiver which controls the equipment through an electro-mechanical interface.

With the invention of fibre optics, mining research organizations began to look for applications underground, mostly in the transmission of large volumes of data. Many difficulties have had to be overcome including determining the kind of data worth collecting. It can be realistically estimated that this technology is a few years from practical use in underground mines.

1.4 Other Considerations

Radio communication for underground mines is a relatively new technology. Because of its technical nature most emphasis is placed on the hardware aspect. It is important to point out here that regardless of the physical make-up of a machine, the final judgement is whether it has been accepted and utilized effectively by the users. The selection of good hardware does increase the chance of acceptance and a good training program and a good maintenance program are absolutely essential. In addition, a champion who overcomes frustrations during critical periods and endlessly seeks improvement in all aspects is a definite asset to success of a new venture.

It is sometimes difficult to visualize the communication system as profit and revenue-generating equipment but in fact, financial benefits have been realized by successful installations. This was accomplished through time saving by rapid reporting of unusual mining conditions and breakdown of equipment.

1.5 Conclusions

Many radio communication systems, from MF to UHF, are on the market for underground mine use. For mine-wide communication applications the frequency modulated, medium frequency (FM-MF) system appears to be the best choice at present. It is easy to install, simple to maintain and offers good quality signal transmission. Capital costs are relatively low. It is proven technology which has been used in Europe for many years.

For data communication many systems are available. Most of these utilize wires. Radio communication, utilizing FM-MF, is also available for monitoring mobile equipment.

Although good hardware is important, it has been found that the systems engineering approach is the best guarantee for a successful installation. The benefits generated by the installation are high. A payback period of less than one to two years for the capital expenditure is not unrealistic.

This report must point out a general lack of research and development in Canada in underground mine communication. Many manufacturers have authorized dealers here, but these do not qualify as Canadian content.

1.6 GENERAL RECOMMENDATIONS

In many parts of the world, particularly in Canada, underground communication is in the testing and fine-tuning stage. There is no standardization and no comprehensive regulatory package to guide the mining industry in selecting acceptable hardware especially in relation to safety. It is recommended that a formal organization be set up to deal with these concerns.

Mine-wide communication systems can increase productivity and this is recognized by most mine operators. Many operators are hesitant to enter the field because of uncertainty associated with the new venture and a lack of high-risk research funds for testing. This was partially solved by government agencies and industrial research organizations providing financing for demonstration projects. Many of these projects failed which reinforced the concerns of mine operators. Research funds should be made available but not confined to the testing of hardware

alone. System engineering should be emphasized.

Most mine monitoring applications at present are confined to environmental monitoring. There is a great need for monitoring parameters related to production and maintenance. These parameters are not readily defined and reliable and inexpensive sensors are not available. R & D effort is needed in this area.

There is a total lack of communication hardware for underground mines from Canadian sources. It is not the purpose of this report to define the reasons but such a study should be of interest to the makers of national policy. They should decide whether there should be more basic research on hardware or whether research effort should be concentrated on short-term, application-oriented projects with imported technology.

1.7 Specific Recommendations

1. The medium frequency inductive system should be selected for mine-wide vocal communication. The Montan-Forschung frequency modulated MF system or equivalent is recommended.

2. The shaft radio system should be separate from the mine-wide system. The FEMCO shaft radio system or equivalent is recommended.

3. Although the power output of the Montan-Forschung radio equipment is lower than covered by CSA standard Z-65, approval from mining authorities should be obtained before pilot test commences.

4. During the pilot test period, effort should be concentrated on vocal communication and data communication attempted only after experience has been gained with the system.

5. To ensure success, a project team with a "champion" project leader should be set up. The mandate of the project team should be to:

    a) Make sure that every user is fully committed to longterm utilization of the radio equipment.

    b) Identify and resolve problems as they occur.

6. A log book should be kept, with daily entries by users and examined by the project leader every day. This logbook should record:

   a) Any 'dead' spots.
   b) Quality and noise of radio signal.
   c) Hardware reliability.
   d) Benefits generated by use of the equipment.
   e) Communication traffic.

7 Equipment suppliers should be required to provide a training program. It may only require ten minutes to learn to use the equipment properly but it is recommended that two persons be trained at the supplier's facility to maintain the hardware.

2. GENERAL REVIEW OF UNDERGROUND COMMUNICATION USAGE

2.1 Introduction

There have been many attempts to apply radio communication techniques to underground mines dating back over 60 years. Radio waves however, do not propagate well underground. Attempts to replace or supplement conventional communications with radio generally met with limited success, especially where mine-wide systems were sought. The evolution of radio technology for underground use and of the understanding of radio propagation underground have been described in several excellent papers and reports. Rather than providing an extensive review of published information the emphasis here will be on why mining operations have pursued radio and data communication, successful applications, and the benefits associated with radio and data communication usage. Although some systems such as SADACS, INIEX and some medium frequency inductive units are capable of transmitting vocal as well as data signals, it is convenient to separate voice from data communication when describing the benefits of these applications.

2.2 Radio Voice Communication

While the need for effective communication between U/G locations and between U/G and surface locations has been recognized for a long time, radios have not been widely used in the mining industry, especially in North America. Equipment capable of fulfilling most of the requirements has become available only relatively recently. The particularly harsh environment and unique operating problems presented by U/G mining have been part of the reason that more advanced communication systems have not been adopted earlier. Uncertainty within the mining industry about the economic impact and benefits of improved communications may also have been a barrier although it may be more a case of "what you don't know exists, you don't miss". Where partial or mine-wide radio systems have been employed some of the benefits can be quantified while others can be described only in general terms but are, intuitively, very substantial:

i) Better utilization of mine supervision - mine supervision can more effectively cover a larger production 'beat'. If additional shiftbosses are being considered in a developing or expanding mine, an effective radio system may make this unnecessary. By being in constant contact with all work areas within a production beat, the supervisor is also better able to visit work areas and address problems in order of priority rather than in arbitrary order. The mine organization can become more responsive; from miners to first-line supervision through to senior supervision, the rate at which decisions can be implemented is increased. The quality of decision-making is also improved because the decisions are likely to be made with more complete information that is also more up-to-date. The very nature of mine supervision may be altered; in one operation observed, supervisory effectiveness improved to the extent that an entire level was phased out of the managerial hierarchy following installation of a radio communication and data acquisition system.

ii) More effective use of manpower working in isolated areas - miners working alone or in isolated areas within mines are of particular concern and occupational health and safety regulations in many jurisdictions require frequent(eg. hourly) contacts by supervision where the miner is working alone underground. In some cases, supervision is difficult in that both the worker and the supervisor are roving. Workers may be assigned partners merely to avoid working alone when technically the job at hand is, a one-person operation. For example, diamond drilling crews typically work in exploration drifts that are quite isolated from main production areas within a mine. While highly mechanized equipment is available for this work, two men are frequently assigned. Where a radio system could be employed to permit constant communication between a supervisor and a diamond driller, this may conceivably translate to doubling of productivity.

Providing individuals and crews with communication links can alleviate the negative psychological effects of

isolation, improved quality-of-work-life may be translated into higher morale and lower turnover.

iii) Increased utilization of mine equipment - a radio communication system can substantially increase equipment availability because mechanical and electrical service personnel can be contacted much quicker when equipment is down. The breakdown of mobile equipment, such as drill jumbo or LHD, may be used to illustrate a typical chain of communication and the associated delays when no radio system is available: Assume that this equipment breaks down at the 'face'; the operator must first walk from the work area to the nearest phone which may be distant. Having reached a phone, the miner must try to contact his supervisor at one or two likely locations but such one-way communication may be inadequate and there might be no way of ensuring that the message will even be received. Assuming that the production supervisor does receive and understand the message, eg. when he arrives at a lunchroom, he might in turn try to contact a maintenance foreman who must in turn contact the appropriate mechanic, electrician, or other tradesman who may be roving in the mine or on surface. Meanwhile, critical production equipment worth hundreds of thousands of dollars may be idle, as is the crew. When a particular mechanic has finally been contacted, his foreman, based on perhaps sketchy information, will assign him to conduct the repair. The mechanic must then travel all the way to the workface after having waited for the cage, so that he may properly diagnose the problem. For even most minor repairs, he must then return to surface (further delay) or possibly to an underground shop area to obtain appropriate tools and parts to effect the repair, and then once again return to the workface.

In the same equipment breakdown scenario with a radio communication system the operator could immediately contact his supervisor and in turn the appropriate service personnel. Supervision could more effectively determine the priority of the work and the mechanic, through 2-way conversation with the operator, determine the nature of the problem (for example - "hydraulic hose to boom cylinder is broken"). The mechanic could then remotely arrange to have the correct part waiting for him at the shaft station and then proceed directly to effect the repair.

Conversely, when either preventive maintenance or unscheduled repairs to equipment have been completed, service personnel can notify operating personnel immediately, thus getting equipment back to work sooner.

The overall effects on productivity and equipment utilization are a function of the degree of mechanization, mine layout and other factors. One highly mechanized multi-level metal mine in Europe reported finding 20% of its mining equipment superfluous for a given rate of production after a mine-wide communication and equipment monitoring system was implemented.

iv) Decreased delays in receiving materials and supplies - the logistics of moving thousands of tons of ore out of a mine and distributing enormous quantities of materials and supplies into a mine can be quite complex. The events and possible delays in getting necesary supplies to a workface could be described in a manner similar to the equipment breakdown example. A radio system could much improve the supply function through the shaft or decline and distribution to each workplace.

If it is conceded that delays could be minimized through an improved communication system, then consideration can be given to substantial savings in capital costs and other carrying charges associated with having excessive inventories of materials and supplies on hand. The optimal "re-order point" in classical inventory modelling could be reduced not only because lead time to get supplies to where they are needed is reduced but also because improved communications can reduce the risks associated with running out of supplies in a particular workplace. Anticipated supply shortages can be reported promptly; when shortages do occur, supplies can be more readily redirected from elsewhere or men and equipment can more readily be redeployed.

(v) Improved Emergency Preparedness - Increased productivity through improved communications can be illustrated by a few case histories in which good economic payback is evident without even considering safety aspects. Communications can also help to minimize the slowdown of work that is often observed following an incident or injury in the workplace. During an emergency situation however, the payback on a radio system may very well be immediate.

In the event of injury or major accident, being able to immediately notify the cagetender or hoistman, first-aid, and supervision minimizes the average time between injury and treatment. Radio systems are more likely than telephone systems to continue providing a communication link following a cave-in, explosion, fire, or other disaster (for example, by inducing the radio signal into air and water pipes, cables, rails, etc.). 2-way inductive radios on vehicles and in work areas is the most practical "trapped miner" system for deep multi-level mines.

Even in situations that do not involve accident or injury, having the radio communication link as back-up to the telephone system can prevent major disruptions to production. Losing the telephone system is an emergency situation in most jurisdictions so that stench gas for example must be used to signal evacuation of workfaces. Even if the telephone system can be restored with little delay, the disruption to the mining cycle in development headings may result in lost rounds. One mine in the Elliot Lake area has reported that the presence of several inexpensive inductive radios underground made it unnecessary to inject stench gas when the telephone cables were accidentally damaged in the main ramp. One incident of this type was enough to more than pay for the radios. Radios should not be viewed as competing with telephone systems; there are synergistic effects from having both. Linking various radio systems together with telephone systems is an area where further research and development is required. A distinction should be made between the ultimate 'dream' communication system and what is adequate and affordable.

In an emergency situation such as an underground fire, mine-wide radio communication offers considerable advantages over stench gas as a warning system. Stench gas injected into the compressed air system and ventilation network often takes a considerable amount of time to arrive at the furthest reaches of a mine and in some cases might go unnoticed by workers. It does not tell the workers about the nature of the emergency nor is it able to provide special instructions. In some underground fire situations for example, it may be desirable to reverse ventilation fans, but this is not possible until all affected miners have been contacted and given instructions.

Some types of radio systems permit the use of earphones and throat microphones so that fire-fighting or mine rescue personnel can keep in constant contact not only with each

other but also with surface even while working "under oxygen" or in extremely noisy surroundings.

Lost production due to fire drills bears consideration since these must be conducted at least every twelve months for each working shift. The disruption to production is a function of the time it takes to notify and account for every person underground. The fire drill procedure could be speeded up considerably if radio communication were used to supplement the stench gas warning system.

Other situations where radio communications could result in time-savings are in locating personnel underground. For example, where it is necessary to locate a person underground because of an emergency at home, it may be possible to contact that person immediately rather than re-assigning personnel to wander seeking that individual.

(vi) Improved General Level of Safety

Intuitively, better communications should translate into a better safety record. Workers can report and be notified of dangerous conditions or locations promptly. Less experienced workers can question their supervisors or safety department concerning appropriate work practices as unusual situations arise. Since advice and supplies are more readily available, make-shift solutions are less tempting. Production shiftbosses and maintenance foremen are better able to provide supervision where it is most needed. One hardrock mine even reported that radio communications helped to save time when disciplinary action was warranted; when penalty or discharge was being considered for drilling too close to a bootleg for example, the usual procedure was to contact second-line supervision or the safety department to witness the infraction. Radios alleviated the problem of contacting specific personnel roving underground.

Radios can contribute to safety in a much more direct way. Whenever close co-ordination is required between personnel working on or near moving equipment and they are unable to communicate directly. Performing the work in a safer manner is always congruent with performing the work more efficently. Examples of these situations include:

- co-ordination of work being done on or alongside a conveyor or mono-rail which may require start-ups.

- raises or underground construction sites such as crusher installations in which men are working overhead.
- shaftmen conducting repairs or inspections of the shaft are able to communicate with the hoistman even between levels.
- cagetenders and deckmen are able to communicate with the hoistman regarding special movements of the cage such as when equipment is being slung under the cage or skip, etc. Specialized hoist communication systems have been operating successfully in many mines for a number of years; numerous references are appended.
- raiseboring crews can co-ordinate work between personnel at the raiseborer itself and personnel at the bottom attaching cutter-head, mucking cuttings, etc.
- miners and supervision can communicate with the fill plant during pours of backfill.
- on tramming crews, motormen and switchmen can communicate even on long trains where they are unable to see each other. Radio communication between motors at each end of a train in place of cap lamp signalling has permitted one Ontario mine to double the number of haulage cars in a given train with an improved level of safety. Numerous communication systems have been installed on trollies underground worldwide, many of which have been documented in the literature.
- the more mobile equipment a mine has, the more likely radio communication is to significantly increase productivity; one highly mechanized hardrock mine has reported productivity increases of up to 15% in an area of the mine where radios have been given to supervisors and installed in repair areas and on mobile equipment.

  Of course, more mobile equipment in a mine increases the risk of collision and delays in production due to queuing. Co-ordination between operators of this equipment can improve both safety and efficiency.

While references are cited in which there have been measurable benefits from radio communications underground, most of the benefits are difficult to quantify. (Indeed, it would be extremely difficult to quantify the value of the telephone on your desk, nevertheless it is by no means a frivolous piece of equipment). Even where overall performance has improved in mines that have installed radio systems, it is difficult to determine exactly which uses have yielded the best return on investment. The importance of good coordination and good relations between the different shifts and between the production department and various service departments cannot be over-emphasized.

In underground mining, a nominal eight hour shift may consist of only about six hours effective work time at the face after allowing for travelling to and from the workplace underground, lunchtime, breaks, personal needs, and miscellaneous delays. If improved communications can save just ten minutes of non-productive time per shift, this represents almost 3% improvement. One must consider further that the incremental cost of achieving this productivity improvement is very low - most of the costs, such as labour, are relatively fixed and would be incurred anyway. The additional revenue generated by 3% productivity improvement will vary depending on the operation, ore grades, etc. but can amount to several thousands of dollars per day for many Canadian underground metal mines.

2.3 Data Communications Usage

It has been said that we live in the Information Age. One must concede that even in the mining industry the timely generation and analysis of useful data is an enormous daily undertaking which occupies much time for a substantial part of the workforce. Manual gathering of data with hand-written or verbal transfer is one of the more primitive methods of communicating data to others but is the predominant method in mining. Information vital to the operation and management of a mine covers a wide range concerning mine environment and conditions, production equipment and personnel.

Use of the data that is gathered and transmitted from underground may be divided into real time monitoring/control system and management information systems; the latter frequently being a subset of the former. 'Management" information may consist of daily, weekly, monthly reporting with respect to ore grades, manpower, environmental conditions, tonnages from various mine sections and may include computer-based record keeping, trend analysis, and reporting. Information reporting can be at several levels - control room staff, supervisors, engineering staff and management.

A simple data communications model may consist of underground section foremen or shift bosses dictating mine status and production information via telephone or radio to a central dispatcher. The dispatcher may in turn be responsible for updating, perhaps on a computer, the data being received from several such sections. The installation of mine-wide radio communications facilitates this type of simple data gathering network. Some systems such as National Coal Board's MINOS and the French 'Televigile' system for example integrate certain management information functions with real time monitoring/control systems. Further information concerning

management information systems can be found in the included references; this report will deal with the actual mine monitoring/control hardware and the present and potential usages of these systems in underground mines. Mine monitoring systems are defined here as electromechanical systems that (a) sense various operating and environmental parameters and convert these to analog or digital signals, (b) telemeter the data by various means to a distributed or central location, and (c) analyze and/or display the data by a variety of means. In addition to monitoring, control signals may be sent from the central location manually by a 'control room operator' or automatically by a microprocessor or computer system. The various types of sensing, telemetering and display techniques will be discussed later and while differing in detail, conceptually the systems are similar.

In general, the coal mining industry has lead the metal/non-metal industry in the adaptation of process control or real time monitoring systems underground. Coal mines, especially in the U.K., France, and Germany were among the earliest to adapt this technology and have used it more extensively. Installed monitoring systems in European mines number in the hundreds; indeed, most mines have some degree of monitoring. In contrast, surveys by U.S.B.M. showed little more than two dozen U.S.A. companies, mostly coal, employing this technology. There are even fewer such systems in Canada, perhaps a function of the relatively small number of underground coal mines. Much of the mine monitoring technology has its roots in monitoring of environmental conditions, methane content in particular. Unlike the more fragmented North American mining industry, mining research in many European nations is much more centralized, bringing more resources to bear on R & D through large organizations such as National Coal Board's Mining Research and Development Establishment (MRDE) in the U.K., CHERCHAR in France, Bergbau-Forschung in West Germany and the Institut National des Industries Extractives (INIEX) in Belgium. By adopting nation-wide monitoring standards, development costs of monitoring systems are distributed over a much larger market. In many cases, regulations in Europe strongly encourage the use of mine monitoring systems. In Germany, mines with continuous monitoring and recording of methane are permitted higher methane threshold values, CO recording in conveyorways is mandatory. In the U.K., regulations permit monitoring of return airways with data telemetered to a control location from which face equipment can be remotely de-energized. While regulations do not directly favour monitoring in the U.S.A., several companies with monitoring systems have been able to petition for 'variances' from the regulations. In Canada, there are no major regulatory advantages for mine monitoring systems known to the authors.

Applications can be categorized into two broad areas: environmental monitoring and production monitoring.

Several of the mine monitoring systems installed in Canada have emphasized environmental monitoring and control of ventilation, at least during initial justification and installation stages. Subsequently, production monitoring is phased in once the microcomputer, wiring and other hardware have been installed.

Additionally, several seismic and microseismic monitoring systems have been installed and are being installed in Canadian mines. These are used for monitoring seismic occurrences in the audible and subaudible range, especially in highly stressed, rockburst-prone mines. While these systems have many technical similarities to general mine monitoring systems, most installations are single-purpose. A detailed discussion of microseismic monitoring is beyond the scope of this report. However it is worthwhile to note that with appropriate computer capacity and system design, a mine that has or is contemplating installation of a microseismic system could incorporate other environmental and production monitoring functions in a very cost-effective manner.

Basically, any information that can be converted into an analog or digital signal can be included in a mine monitoring system. The limitation to date has been the availability of reliable sensing devices to perform these functions under severe mining conditions. This has been recognized by agencies such as CANMET, MRDE and U.S.B.M., that have done considerable work on developing sensors. Most of this work has been coal industry oriented. Development of a wider range of reliable sensors for hardrock or non-coal applications is an area requiring further research and development.

2.4 Environmental Monitoring/Control

The objective of environmental monitoring is to provide centralised, continuous monitoring of all aspects of the mining environment and to automatically report abnormal or alarm conditions. A further objective is to control certain parameters, for example fans speed, either automatically or by a control room operator. Parameters monitored include but are not limited to:

- ventilation fans - monitor status (on/off), power drawn, temperature and vibration of main fan bearings; remotely

control blade pitch, automatically turn off or reduce fan speed during off-shift and on holidays or weekends according to a pre-programmed schedule.

- airflow - monitor air velocity in critical intake drifts.

- pressure - monitor natural and fan ventilating pressure, compare to seasonal model.

- humidity - measure relative humidity in intake and exhaust airways.

- temperature - measure air temperature in downcast shafts, main ventilation drifts.

- heaters - monitor status, power or gas consumption, automatically control mine air heaters (eg. to prevent shaft freezing); programmed control for off-shifts, weekends, etc.

- coolers - in hot areas or deep mines, monitor and control function of mine air coolers.

- ventilation doors and regulators - monitor status (open/closed), remotely control doors and regulators to optimise ventilation system

- gases & dusts - monitor concentrations of critical gases and "designated substances" required by regulations to be regularly surveyed; provide alarms and automatically take appropriate action such as remotely shutting down mining equipment, adjusting ventilation; parameters include:

    - methane
    - NOx
    - CO_2
    - CO
    - oxygen deficiency
    - radon
    - designated dusts
    - fire detection (both U/G and in surface buildings)

- fire suppression and alarm - detect and locate fire, trigger suppression systems and alarms, stench gas injection.

- Management Information - print out end-of-shift summaries, trend analyses, reports with varying degrees of detail pertaining to:

    - any alarm conditions or unusual events
    - average methane content

- average air quantity
- system maintenance, etc.

Benefits of environmental monitoring:

The largest benefits in Canadian mines are reported in the automatic control of ventilation systems. Higher quality mine atmosphere can result in lower turnover, a more productive workforce as well as more efficient diesel engine operation. In cold climates, microprocessor-control of the mine ventilation system is reported to have provided about one year payback in at least two of the underground operations visited with about $100,000 savings in annual propane cost alone.(one using Conspec, the other Modicon) Conversely, in a hot climate, control over mine air cooling using an Outokumpu monitoring system yielded very attractive payback.

As mentioned, in some jurisdictions, higher threshold values for methane are allowed or other regulated requirements waived if continuous monitoring is in place. The effect this can have on reducing 'nuisance' production stoppages is considerable and far more importantly, there is a much higher likelihood that mining disasters can be prevented.

Certain gases and airborne dusts must be frequently sampled for, reported on, and in some cases daily time-weighted exposures for each work area calculated. While the gases to be tested for may vary with the type of mine, presence of diesels etc. two things are apparent for all mines:
1) continual sampling is labour intensive and 2) the number of substances to be sampled for that are required by law will likely increase in number rather than decrease. One mechanized Canadian hardrock mine reported that by installing additional sensors in their existing Modicon mine monitoring system, they were able to comply with new regulations (requiring sampling of additional substances) without having to hire one or possibly two full-time technicians.

The benefits of automatically detecting a fire and plotting its location in an underground mine are self-evident. This has been of particular interest to South African mines where timber props are used for support and fires have occurred due to spontaneous combustion. A CANMET-developed carbon-monoxide analyzer installed several years ago in a mine monitoring system in western Canada was credited with detecting the onset of heating (indicated by a significant increase in the level of CO). This warning permitted the mine to take remedial action without interruption to the mining schedule.

Automatic control of ventilation systems can reduce the amount of 'excess' air typically provided to compensate for changing conditions, not only seasonally but on a daily basis. The total labour effort to check ventilating equipment can be much reduced also. One mine, in which a large amount of ventilation (and heating) is required (over 2500 m^3/sec.), is located under a lake and intake fans and heaters are located on an island. Previous to the installation of a CONSPEC monitoring system, checking the equipment required personnel to travel to the island (boat, snowmobile, hovercraft) hence adjustments to accommodate minor daily variations were simply not done. Now the system is monitored and controlled remotely so that heating energy is optimised. Another multishaft metal mine in northern Ontario is utilizing mine ventilation software developed by M.I.R.O.C. (Mineral Industries Research Organization of Canada) to optimise the ventilation system on-line.

2.5 Production Monitoring

The objectives of production monitoring are to obtain accurate, objective measurements of production, performance of equipment, and other operating parameters and to store these data for subsequent use in a management information computer system. Where feasible, remote or automatic controls can be applied to remove personnel from environmentally undesirable locations. Applications in operating mines include:

- conveyors - on/off status, speed, power draw, belt tension, record weightometer measurements, monitor and provide alarms/shutdown for belt slippage, belt tearing, belt misalignment, tramp metal on conveyor, etc.
- centralized video monitoring - at skips, conveyors, crushers, and surface installations at the mine.
- detection of levels in bins, ore passes, waste passes, etc.
- compressors - monitor operation - bearing temperatures, pressure etc. and control remotely.
- backfill - monitor the volume and quality of hydraulic tailings fill on-line, detect spills of fill in untravelled areas.
- pumps - monitor on/off status, pressures, high and low levels of water or leaching liquor, sump levels.
- electrical power system - monitor total and peak power draw, detect and locate electrical faults
- rock mechanics instrumentation - remotely monitor and record readings from extensometers, load cells, bulkhead pressure guages, movement monitors, geophones, etc.
- vehicle location (track and trackless) - remotely monitor and display location of all vehicles in the mine; automatic guided vehicle systems.

- engine parameters - monitor and record various engine parameters such as:

  - temperature
  - oil pressure
  - operating hours
  - time down for repair

- Management Information - automatically print out end-of-shift, weekly, monthly summaries, trend analyses and reports with varying degrees of detail pertaining to:

- tonnage hoisted, production by level or section
- major delays, unusual events
- backfill placed
- energy management report
- vehicle availability, utilization, maintenace analysis, etc.

Benefits of Production Monitoring:

Most mines employing production monitoring report good return on investment in conveyor systems. This is because conveyors present a stationary, relatively straightforward application for monitoring and control and represent very high capital investment and are critical to production. Various types of devices can be used to monitor situations which may threaten damage and disrupt production; belt slippage and misalignment sensors have been installed on hundreds of conveyors both underground and on surface. Some mines not having more general monitoring systems, recognized how sensitive the operation is to conveyor damage and have installed simple programmable controllers locally. A more recent development observed are systems to detect belt tear or slitting. Wire loops can be inexpensively vulcanised in place at given intervals into conveyors and the loops detected by an inductive RF system. A belt slit would be detected and the conveyor automatically shut down. These systems have been installed in mines in Europe as well as Central and South America. The value of such a system depends on the length and type of belt as well as the potential cost of lost production if a belt were destroyed. For many mining operations, this is substantial.

Closed circuit video monitoring has had good acceptance in mines for some time. Advances have made it possible to transmit the video signal over twisted pair telephone wires or by radio frequency carrier and this has made centralized video monitoring in mines much more attractive. Rugged units are available that permit remote panning and zoom using a simple joystick. Relatively inexpensive microwave links are also available for

connecting distant surface facilities . Typical installations allow one person to view several units of automatic equipment such as skips, conveyors, crushers, etc. thus freeing machine attendants to do productive work. The payback is often very rapid. One mine added video surveillance of the parking lot, gate, and materials yard to an existing mine monitoring system. The control room operator, who now acts as a remote gatekeeper, is able to videotape entries and exits from the property. The virtual elimination of parking lot vandalism and yard pilferage alone has justified the system, but that is obviously the least of the benefits.

Remote level detection in storage bins, ore, and waste passes is possible by a variety of methods including ultrasonics, radio isotopes, and rod probes. The benefit is being able to anticipate and thus avoid becoming 'muckbound' or pulling chutes completely empty. From the safety point of view, hangups can be detected and remedial action taken to avoid a possible dangerous run of muck. One mine backfill plant reported that once rock and sandfill bunkers were remotely monitored, they were able to challenge the trucking contractor's claim for standby charges due to full bins or because no load was available leading to considerably lower trucking charges and no delays in pouring backfill underground. Other backfill plants remotely monitor and record volume, pulp density, and cement content and ensure proper quality of fill while avoiding the expense of excess cement.

By monitoring pump volumes, it is possible to determine the water balance in bulk pours so that dangerous build up of water behind bulkheads can be avoided. The ability to monitor pumps with respect to on/off status, high and low water levels, etc. is of particular interest to mines that 'make' a great amount of water or that do bulk fill pours. Flooding and damage to equipment can be avoided since diagnostics are included (i.e. location and type of problem instead of a red light for all alarm conditions) and there is less need to call out personnel on overtime to take care of alarm conditions.

Compressors can be monitored and controlled by a micro-processor. One large U.S. metal mine found that a bank of compressors was running sub-optimally. Their control system now has fewer compressors running at any one time and compressors are operated in rotation. The compressed air distribution system is monitored and pipe ruptures or valves left open can be detected. Demand is continually monitored so that auxiliary compressors are activated only when required. Logs of compressed air costs

indicate that the system had a payback period of a "few weeks".

Similarly, monitoring of the electrical distribution system offers the opportunity to manage energy consumption through 'peak shaving', which can have very high economic impact. Electrical faults can be detected and located remotely, increasing safety and reducing time required to for maintenance. One mine reported their remote monitoring and control system may have saved a miner's life when the chute he was barring began to run causing the bar to short circuit a D.C. trolley line and trapping the miner up in the pony set. The fault was alarmed on surface and power was immediately cut.

Rock mechanics and other instrumentation underground, if extensively used, require considerable manpower to take readings. Remote monitoring not only allows readings in dangerous or inaccessible areas but also provides continuous readings and may highlight significant changes or trends.

Instrument readings on mobile equipment can be telemetered to a central computer via radio transmitter. The on-line recording of vital engine parameters such as oil pressure, temperature and operating hours is of great importance in a computerized maintenance analysis system. An Austrian metal mine using a Montan-Forschung monitoring system also permitted the machine operator to input information via a keypad - drawpoint, dump-point, number of loads, downtime, etc. As well, infra-red position sensors in main haulageways allowed the central control room operator to know the location of critical production vehicles at all times.

Not to be overlooked are the benefits of integrating computerised management information systems with real time production monitoring. Consider the amount of time that crew leaders, mine clerks, supervision, and technical staff spend preparing routine reports on the day-to-day operation of the mine. Furthermore computerised 'massaging' of information frees mine managers to manage-by-exception rather than becoming buried in mountains of information.

Radio communications and mine monitoring systems are seen in many operations mining low grades of low-priced minerals in an extremely competitive industry. Most report that these systems are installed due to economic necessity. One such mine embarked on a program of economic survival three years ago which included mine monitoring and control, increased mechanisation, and radio communication. The mine has since reduced its workforce by about two thirds while maintaining production at the same level.

2.6 Safety Aspects of Underground Communication

Of concern to mine operators is the potential hazard of using radio transmitters underground near explosives and especially near electric detonators. Fears are compounded in mines where a centralised blasting system exists in which a blasting cable network could conceivably act as some sort of antenna, drawing radio frequency energy directly to a loaded, wired face.

This problem has been studied by a number of agencies including the Franklin Institute Research Laboratories in the United States and CERCHAR in France. In Canada use of radio transmitters underground is regulated by Provincial Mining Acts; Ontario and Manitoba for example, both refer to the Canadian Standards Association's CSA Standard Z-65, "Radiation Hazards from Electronic Equipment".

Falconbridge Ltd. as well as other mining companies have conducted tests in accordance with CSA Z-65 on various radio transmitters. Even units of several watts power (an order of magnitude greater than the radiating power of the newer medium frequency radios from Europe) were all found acceptable for underground use. Most of the units tested however were at VHF to UHF frequencies; work done by the Franklin Institute (1969) indicates that the RF sensitivity of both instantaneous and delay blasting caps can be frequency-related. It would be necessary to perform these tests with medium frequency transmitters to confirm that they meet requirements.

Concerning the danger of premature firing of detonators cited at the same conference: "This question has often been examined by CERCHAR, often at the request of the administration. The reply has always been that the probability of danger was nil.

We have thought a good deal about this question and it has also had the attention of the inspectorate...basically the transmitters are always of very low power, perhaps 2 watts, and in practice it is absolutely impossible for such a transmission to fire a detonator owing to the complete difference in impedances. Obviously, if you connect a detonator through a connection made by an electrician between the transmitter and detonator, it can be made to fire, but it is impossible for a

connection producing this result to occur accidentally.

Portable transmitters sometimes radiate power capable, of setting off a detonator, but this power can only be received by lines with characteristic impedance of about 200 ohms. The impedance of a detonator is about 2 ohms. The line, which in any case can only receive a very small fraction of the energy radiated, can only supply the detonator with 1/100th of this fraction - nothing approaching the power required...all experiments have shown the impossibility of premature firing."

3. VOICE COMMUNICATION SYSTEMS

3.1 Introduction

Voice communication systems fall into two general categories:

(a) Hardwired systems including sound-powered phones, paging phones, and private branch exchange (PBX).

(b) Radio systems, wireless, with no direct connection between stations.

This chapter focuses on the most popular of those systems used in Canadian mines. A brief description of the principles of operation and a review of some typical installations is included.

3.2 Hardwired Systems

These systems depend on a wire connection between stations to carry the voice signal. A single telephone is connected to one or more telephones, allowing for conversation from station to station or station to multiple stations. The connections can be made directly with a single pair of wires between telephones or indirectly with a telephone exchange providing the link.

3.2.1 Sound-Powered Handsets

These handsets need no energy source other than the speaker's voice to function. Two sets are connected together via a single pair of wires and can provide good communication over short distances. Their rugged construction makes them well-suited for the underground environment. Installation is easy since there is no polarization problem which would require tracing the pairs of wire used.

3.2.2 Battery-Powered Handsets

These new transistorized handsets need minimal power to function (two penlight batteries). They provide amplification of the voice signal thus extending the distance over which they can be used. A button-activated built-in buzzer emits a loud tone advising the other station

of an incoming call. Because of lower power requirements, several phones can be connected to the same line without overloading the circuit. They are also water resistant.

3.2.3 Pager Phones

Pager phones operate in a way similar to intercoms. A two-wire line links all units and a connection can be made between two or more stations. The advantage of this system is that a special circuit allows the caller to broadcast or page his party using a loudspeaker system connected to the phone. When the party answers the call, the loudspeaker drops out of the circuit limiting the conversation to handsets. This system is simple to install and use and easy to maintain. The limiting factor on the distance at which the system will function is the ability to turn on the paging amplifier. This will vary with line size, connections and signal levels. New designs eliminate the paging problem using a DC signal on the line by sending a modulated carrier. Besides increasing the range, the modulated carrier system allows the phone to be connected to the same wires used for other pager systems.

As a mine increases in size so will the number of phones which does not necessarily imply a better communication system. Indeed, one disadvantage of these phones is that they use a party line system and thus the line could be tied up for long periods of time with conversations involving maintenance problems, restricting its use by other parties. In noisy areas, a flashing light is sometimes added to the loudspeaker to attract attention when a page is underway.

3.2.4 Private Automatic Branch Exchange (PABX)

The extension of the regular surface telephone system underground provides some advantages over the hardwired systems. It allows for selective calling, station to station, and the capability of a multitude of private lines.

With the advent of solid state exchange, specific features can be incorporated into the telephone, such as conference call, restrictions on outgoing lines, or destinations accessible from underground, addition of code calling capabilities. Conference calls allow a three-way conversation to take place or a third party to be consulted during an ongoing conversation. Restrictions are sometimes

placed on telephones dedicated to specific uses. This tends to keep the frequency of calls handled by that phone to a minimum since only a given set of numbers is accessible from that location. For underground use, the normal telephone set is not rugged enough and must be protected by a dust-tight shock-absorbant enclosure. Mine phones, designed for use underground, are available from several manufacturers. They are suitable for use with the most modern microprocessor-controlled PABX, and in some cases comply with the intrinsically safe specifications for use in hazardous locations.

3.2.5 Distribution Media

For hardwired phones, the distribution of signals is via a single pair, multipair or a multiplex system. The fact that an actual connection exists between telephones makes the system unreliable. Indeed, if a line is broken or shorted by a rock fall or a piece of mobile machinery, all telephones beyond that point are affected and the whole system in jeopardy.

A - Single Pair Cable

This is the minimum required for sound-powered phones and paging phones. The wire size is usually between 1.3 mm^2 (#16 AWG) and 3.3 mm^2 (#12 AWG). This is quite large compared to .324 mm^2 (#22 AWG) used by PABX but reduces signal losses over longer distances. Cable manufacturer's specification sheets usually show attenuation charts indicating losses in decibels per kilometer at different frequencies for a particular cable. Besides losses, electromagnetic interference can affect the quality of signal being transmitted. If the conductors are placed in the presence of a rapidly varying field caused by high powered rectifying electrical equipment for example, noise can be induced in the conductors affecting the signal quality. This problem can be eliminated by the use of shielded cables where the conductors are surrounded by a conductive shield (wrapped mylar foil or braided copper) effectively containing outside electrical and magnetic fields.

B - Multiple Cable

This cable is used where several signals are transmitted in parallel. Usually shielded to prevent electromagnetic noise from adjacent sources, the cable is constructed in such a way as to ease installation and troubleshooting procedures. Each wire is colour coded with pairs using complimentary colours and usually twisted.

The mechanical characteristic of cables used underground is important since cables must withstand attack from corrosive and abrasive atmosphere as well as accidental hits by equipment or rock. Manufacturers provide different types of armour which can be wrapped around the core. It can be made of twisted steel wires in which case it does not need an outer jacket unless specific corrosion problems are expected. This type of armour adds to the self-supporting strength of the cable so that a single length of 1,200 metres or more can be installed in a shaft by unrolling it from the reel. If protection is required but steel wire makes installation difficult because the cable is not easily bent, other armours ranging from spirally-wound steel or aluminum (TECK type) to single or double welded tapes of aluminum, copper or steel (PASP type) can be obtained. These are then covered by a P.V.C. or a polypropelene layer. The core of these cables can be filled with a flooding compound to prevent water and moisture intrusion.

C - Multiplex System

When several signals are sent simultaneously on the same wire or pair a method must be provided for combining these signals at one end and separating them at the other. Two methods are used: frequency-division and time-division multiplexing.

Frequency-division multiplexing is when several signals are sent over a common line by using a separate frequency for each signal. Each voice signal is applied to a modulator which gives it its own frequency and demodulated at the other end to revert it to its original voice frequency.

Since communication systems are two way, the same structure exists in the reverse direction.

Time-division multiplexing uses a time-sharing concept where on a single line, time slots of very short duration are allocated to different signals. For example, during time slot 1, signal 1 is connected to the line, and during time slot 2, signal 2 is connected to the line. The process is then repeated. The resulting signal on the line is a combination of signals 1 and 2 following each other.

D - Co-Axial Cable

This cable consists of an inner conductor and an outer conductor, the inner being separated from the outer by an insulating layer. The co-ax has lower attenuation than a twisted pair and because of the outer conductor, (shield), is less affected by cross talk and electromagnetic interference.

E - Fibre Optics

Fiberoptic cable consists of a glass fibre of very small dimension surrounded by another glass layer of a different composition such that a light signal sent down the fibre will be trapped in it, minimizing losses. Since signals are in the form of light rather than electrical impulses, they are not subject to electromagnetic interference or noise. Shielding and grounding are not a problem. The signals are transformed from electrical to light by use of a light-emitting-diode (LED) and at the other end from light to electrical by a light-sensitive diode or photodiode. The same principles of multiplexing exist here as with the electrical signals. The cables are lightweight and easy to manipulate.

Although fiberoptics have been on the market for some time, it has not found wide spread use in mines. There are two main reasons for this. First the cable although immune to electrical noise, is not as mechanically sturdy as one would like underground which means that an extra cost must be incurred to provide adequate armour. Second, in the event of a break of a fibre, personnel with specialized equipment must be brought to repair and splice it, adding to the length of downtime. Possible production losses and additional cost. These drawbacks are well known and are being investigated by research institutions such as the

National Coal Board's Mining Research and Development Establishment (MRDE) in Bretby, England where a new type of connector is being investigated to eliminate difficulties arising from having to splice a fiberoptic cable in a wet shaft or a dusty environment for example.

3.3 Radio Systems

Radio systems do not depend on a wire connection between transmitter and receiver. Two basic methods are used for transmission: amplitude modulation (AM) and frequency modulation (FM). Voice signals are used to modulate a much higher carrier frequency which can be transmitted with a very short antenna.

3.3.1 Amplitude Modulation

Here, the amplitude of the carrier varies with the voice signal. The signal shape of the carrier retains the information from the voice signal but is much easier to transmit because of its high frequency.

3.3.2 Frequency Modulation

With this technique, the frequency of the carrier is made to vary with the voice signal. When the amplitude of the voice signal changes, the frequency of the carrier changes. The rate of frequency change of the carrier varies with the frequency of the voice signal. Thus the amplitude of the carrier frequency is always constant. This means that any amplitude variations that find their way into the FM signal can be safely removed because the desired signal information has nothing to do with amplitude changes. However, noise and interference can produce FM interference components so that the system is not completely noise free. Fortunately deviation of the FM signal caused by the modulating wave is much greater than any deviation caused by noise and interference thus pushing noise far into the background. The advantage of FM over AM is becoming important in underground mining operations because of the tendancies toward automation and use of noise-generating electrical equipment particularly vehicular machinery with ignition systems and large electric motors. Another advantage is that FM does not require significant audio power since the signal is in the frequency.

3.3.3 Distribution

Propagation of radio signals is in the form of electromagnetic waves through air. These waves also travel in empty space and under certain conditions through the

earth. The travelling speed of the wave is given by the product of the wavelength and the frequency of the wave. In a given medium, the speed of electron magnetic radiation is constant, thus wavelength and frequency are inversely proportional. The speed of the wave will be reduced if it is travelling in anything other than free space.

3.3.3.a Antenna Theory

In normal electronic circuits the physical size of a circuit is small compared with the wavelength of the frequencies being used. When this is the case, most of the electromagnetic energy stays in the circuit itself or is converted into heat. However, when the physical dimensions of wiring or components approach the size of the wavelength being used, some of the energy escapes by radiation in the form of electomagnetic waves. Antennae can be considered as special circuits designed so that a large part of the energy input to the antenna will be radiated as electromagnetic energy.

Usually an antenna is a straight section of conductor, either a wire or hollow metal tubing, which is suspended in space. When a radio transmitter is connected to the antenna, rapidly varying electrical currents are set up in the antenna. These currents cause electromagnetic waves to radiate from the antenna and travel through the atmosphere or other surrounding medium. When these waves strike another antenna they induce electrical currents in it similar to the current flowing in the transmitting antenna. These currents, although very small if the antennas are far apart or if they are transmitting through the earth, can be amplified by electronic circuits (receivers) to reproduce the original signal. The range of radio distribution systems can be extended by leaky feeder cable, or by using induction properties into existing metallic structure (Carrier Current Systems).

- Half-Wave Dipole Antenna

The strength of the electromagnetic field radiated from an antenna is proportional to the amount of current flowing in the antenna. It is, therefore, desirable to make the current as large as possible. This can be accomplished by adjusting the length of the antenna so that it resonates at the operating frequency.

If a straight wire, or antenna element, were to be suspended in space, the lowest frequency at which it would resonate has a wavelength of twice the length of the wire.

When used to transmit or receive radio frequency energy at a wavelength twice its length, the wire is known as a half-wave antenna.

- Quarter-Wave Antenna

An antenna may also be a quarter wave in length. This is possible because of its connection to ground, which electrically acts as the other quarter-wavelength. The ground plane reflects the quarter-wave antenna so it has electrical characteristics similar to those of a half-wave antenna.

An antenna of this sort may be an odd multiple of a quarter-wavelength. These antennas are commonly used for low-and medium-frequency applications.

- Loop Antenna

Loop antennas can be utilized for through-the-earth radio transmissions or as receiving antennas in direction-finding systems. They can be composed of one or more turns of wire on a round or square form, or the loop can be established by laying the wire in a loop on the ground or floor of a mine tunnel. These antennas are used mostly for low and medium frequency systems.

3.3.3.b CTV Systems

CTV (Community Television System) uses the principles of co-axial cable for low loss transmission of the radio waves and radiating antennae at regular intervals (100 meters). Since the cable nevertheless attenuates the signals with increasing distance travelled, amplifiers must be inserted in the line when the signal reaches a predetermined level (500 meters). When poor coverage is found, it is simple to add an extra antenna.

3.3.3.c Leaky Feeders

As in the CTV system, signals are carried over a co-axial cable designed to leak electromagetic radiation in the area surrounding it. Leakage occurs through machined holes or through the loosely braided shield surrounding the core. (Figure 3.1). Here again, over distance, the signal is attenuated and amplifiers must be added to obain further coverage.

LONGITUDINALLY SLOTTED

LOOSE BRAID

TRANSVERSLY SLOTTED

FIGURE 3.1 LEAKY FEEDER TYPES

3.3.3.d Repeaters

Two types of repeaters are used. First, a single frequency repeater which functions as a signal amplifier in which the attenuated signal is detected, amplified and retransmitted. The frequency of the received signal is the same as that of the transmitted signal. Isolation must be maintained between the two functions to prevent the transmitted signal from being received and amplified by the same unit leading to an uncontrollable feedback problem which could destroy the signal. Directional antennae could be used to avoid this problem.

This is why a different type of repeater is favoured, the double frequency repeater. In this case, the receive and transmit frequencies are far enough apart that no feedback problem exists. The repeater receives the signal at frequency F1 and retransmits an amplified signal at frequency F2. Thus all portable (walky talky type) mobile and fixed radio units would transmit at F1 and receive at F2.

Variations on this arrangement are common. For example the portable units can be capable of transmitting on F2 as well as F1, thus allowing direct portable to portable communication. The repeater can also be used as a link to other communication systems such as a PBX and pager phone. This extends the range of the system. In this case the repeater must be hardwired to a special interface to gain access to the other systems.

3.3.4 Carrier Current Systems

Any underground wire or cable, when fed an RF signal, tends to distribute that signal throughout its length. Carrier current systems utilize this fact to establish communication paths using existing mine wiring. The wire used may be an AC or DC power line, neutral lines such as the hoist rope, existing phone lines, or other wiring.

Carrier current devices are basically radio transceivers that transmit and receive over existing mine wiring instead of using an antenna system. The low and medium frequency ranges propagate best in carrier current systems. An example is the shaft communication systems that utilize the hoist rope to establish communications to and from the cage. The most modern system, based on medium frequency, promises to be the most effective and is discussed in Chapter IV.

3.4 Communication System Examples in Canadian Mines

One cannot claim that there is a best system because all mines are in some ways different. Mining practices vary as does the equipment which in most cases is adapted to suit the particular situation. The example described represents a selection based on user satisfaction rather than simple technical characteristics. Very few of the mines visited during the course of this project possessed personnel capable of trouble shooting, t ing and repairing radio equipment.

3.4.1 Mine A

Mine A is a multilevel metal mine. Ore is mined using a blasthole method and transferred via trolley to a hoist in a second mine at the 4000 and 6000 levels. Once the stopes are mined out, cement fill is poured for ground support.

Underground communication is provided by a telephone exchange. Telephones are located in key areas such as refuge stations, garages, and repair shops and underground hoistrooms. All underground phones are restricted to the mine area.

When filling, miners use battery-powered handsets. Hooking the sets to the line is a fairly straighforward procedure. If intermediate connections are necessary the electrical department provide assistance. When the link is established, the filling procedure can begin. The handsets used, the P12 Echophone, are water resistant and very rugged. The type B from the same manufacturer was tried and although cheaper, could not withstand the underground environment.

The trolley systems on the two levels have two locos at each end. When the front is pulling, the rear is not powered. Signalling between the front and rear conductors was done by waving cap lamps. This restricted the number of cars being pulled to the distance at which the lamp is visible. This distance would vary enormously and whenever particles were in suspension in the air this method was totally impractical. A link was designed using 800 MHz walky talkies from Motorola.

The walky talkies with a 4.5 watt output were tested over the length of the haulageway. Because it is a relatively straight tunnel perfect reception was achieved at distances over 600 metres. The walky talkies were then

installed in steel enclosures and an indicating light added to show that a call is being received. The antenna was placed on top of the enclosures which were made such that they can be removed from the loco and carried to a problem area such as a derailment.

The system is performing extremely well and has permitted nearly doubling the number of cars composing a train.

The ore hoisting shaft is equipped with a leaky feeder system (VHF) for shaft inspection. This system replaced pull cords that used to be hung between levels. The inspecting team is in constant contact with the hoistman. An incident in the shaft tore the cable from its normal position over a length of approximately 100 metres. The cable had enough self supporting capability that it did not break and continued to operate. Regular walky talkies are used and a mobile unit from Motorola is used as the base on surface.

3.4.2 Mine B

Mine B is a multilevel metal mine. Because of a particular interest in communication and awareness of the benefits in efficiency and increased safety, the mine decided to test a CTV system. Previously, a leaky feeder system had provided excellent communication in the shaft but was not considered for production areas because:

(a) Radiax cable is expensive.

(b) Radiax cable is somewhat difficult to install. It must not be kinked or crimped and the outer waterproof jacket must not be installed near power cables, necessitating a separate mounting/clamping system.

(c) communication is possible only at a relatively short distance from the Radiax cable (about 15-25 metres maximum).

The CTV system base station was located underground in the diesel and car repair shop and approximately 1,000 metres of cable installed on a level and down a ramp. The complete system consists of a repeater base station, a distribution network, and mobile and portable transceivers. The repeater base station is a standard unit with the power amplifier removed. The output signal (150.5 MHz) is filtered, impedance matched and down converted from

150.5 MHz to 24.25 MHz. It is then amplified and connected to the input/output duplexer for transmission to the end of the system. A received VHF signal (155.4875 MHz) from the base is sent to a remote console via a telephone cable.

The transmitted signal (24.25 MHz) is fed onto the CTV co-axial cable. Antennas located at approximately 100-metre intervals, consist of a standard VHF antenna mounted on a 15 cm x 15 cm metal plate. About 500 metres from the base, a bi-directional amplifier is installed which amplifies the 24.25 MHz signal from the base as well as the 150.5 MHz and 155.4875 MHz needed for the portables.

Thus the base station sends out 24.25 MHz to the end of the cable. That frequency is converted to 150.5 MHz and sent back via the cable but is transmitted to the portables via the antennas. The transmitted signal from the portables (155.4875 MHz) is sent back toward the base via the cable, received and retransmitted at 24.25 MHz down the cable. This circular arrangement of the signal transmission allows for repeater operation of the system.

Once commissioned, the system performed well. Clean communications are provided within the entire installation. The system is easily expandable and can be interfaced with the telephone system. Television signals can also be carried by the same cable. For communication in a stope, a section of cable terminating with an antenna is brought to the entrance.

Although technically very good and fulfilling its purpose, the system had some operational flaws. Everytime a blast was to be set off, care had to be taken to remove cable and antenna from the stope entrance. The system was introduced by a nonproduction group to a production group and was not very well accepted. The number of connections required to amplifiers, antennae, couplers, and splitters is large, increasing the chances of problems. Not all standard walky talkies can resist the underground environment. The operators were in general satisfied with the system since these technical problems can be overcome. The problems with it are related to cost and acceptance level and are discussed in a later chapter on successful implementation.

3.4.3 Mine C

Mine C is a single level nonmetal mine. The mine is highly mechanized using a continuous mining process. The underground workings are extensive and personnel movement is with vehicles to distances up to 10 km away from the shaft.

Typical tunnels are 6-8 metres wide by 5-6 metres high. A VHF communication system using repeaters and two-wire line between repeaters is used. Repeaters are located approximtely 100 metres apart. The system provides mine-wide communication and an efficient means of contacting service personnel when required.

Despite the fact that the system works well, the operators feel that it breaks down too often with the weak part being the repeater. It uses relatively old technology and does not seem able to withstand the underground environment. Another cause for dissatisfaction is the lack of training of the service personnel in communications.

The mine is investigating other systems to replace this one with particular emphasis on training from the manufacturer.

4. MEDIUM FREQUENCY SYSTEMS

4.1 Introduction

Generally, mobile communications are achieved by radio equipment using RF propagation through space. However, the underground environment with restrictions in tunnel sizes and the numerous curves, corners and branches restrict the distance travelled by the signal.

4.2 General

For a certain range of frequency, commonly low frequency and medium frequency, signal propagation is supplemented by inductive coupling to conductors, pipes and metallic structures in the mine. This phenomena has been studied extensively and has led to advances in underground communication.

The electromagnetic signal transmitted through air induces a current in metallic structures making an antenna out of them. Thus the carrying medium changes from air to cables, pipes, etc. Cables are usually present throughout, going around corners, from level to level, spanning the whole mine from surface to the deepest level. Wherever these cables are present, so is the modulated current. The current flowing through the cable sets up a magnetic flux around it which varies in strength with variations in the current. When the antenna of the portable or mobile unit cuts the magnetic flux, a voltage is created which varies with the RF signal. A good quality receiver is capable of detecting the signal and transforming it back into an audible one. (Figure 4.1 and 4.2)

Transmission from the portables and mobiles is in reverse fashion with the varying flux created at the portable antenna and inducing a current in the cables. The current is subsequently received by the base station antenna.

Early applications of these principles were for shaft communication. Induction was in the shaft cable or power conductors in the shaft.

M.S.A. had a hoist phone working in 1953 with an induction loop around the shaft cable in the headframe and connected to a base station in the hoistroom. Another loop was installed above the cage. The system was used mostly for shaft inspection. Variations on this technique were developed by M.S.A., Funke and Huster, Femco/National Mines Services, and

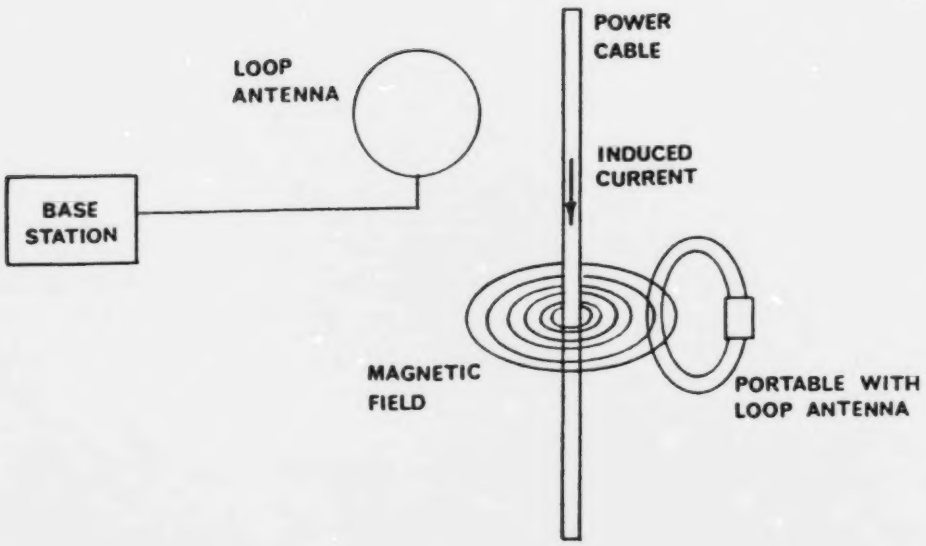


FIGURE 4.1 LOOP ANTENNA SYSTEM

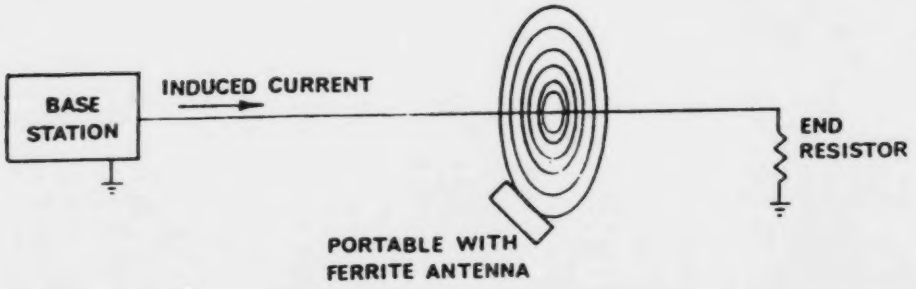


FIGURE 4.2 SINGLE WIRE ANTENNA SYSTEM

can now service both cages and skips.

4.3 Medium Frequency Equipment

The systems mentioned so far are called direct-coupled because an antenna surrounding the carrier cable is used at both ends.

By replacing the direct-coupled antenna with a lighter antenna carried by a miner, one would expect that a fully portable radio can be made.

A summary of the medium frequency systems characteristics is shown in Table 4.3.

4.3.1 Substrata System

In 1973, the Chamber of Mines of South Africa developed a radio system which did not need direct coupling to a conductor to receive and transmit voice signals. The base station used a loop antenna (30 metres circumference) which had to be installed on the back (or roof) of the tunnel with the plane of the antenna parallel to the conductors or pipes it was coupling into. The base was equipped with a remote microphone, had capabilities of a hard wired connection to a remote console, volume control, and tuning. Tuning was necessary because the physical shape of the antenna depended on the installation thus altering the inductance of the loop and affecting coupling. The proximity of conductive masses (metal boxes, conductive ore, etc.) also affected tuning.

The portable unit weighed approximately 1 Kg and also possessed a loop antenna. It was a multi-turn (7 turns) copper wire loop covered with P.V.C. and used as a carrying strap for the portable. Three control switches were on the portable:

1. On/Off switch.
2. Press-to-talk switch.
3. Call switch. When depressed, a high-pitched note acting as an alerting signal was emitted and could be used to transmit codes.

The system used amplitude modulation in the frequency range of 100 KHz to 1,150 KHz and at a 10% transmit to receive time ratio, the batteries would last a full eight hour shift. The reach of the system was claimed to be 1.8 Km between base and portable. An increase in the reach is

TABLE 4.3 SYSTEM CHARACTERISTICS OF MEDIUM FREQUENCY EQUIPMENT

Base Station	NAGANO	SILEC	MONTAN-FORSHUNG	PLESSEY
Frequency (KHz)	150-250	100-1,160	120-600	2,500-3,500
Modulation	AM	AM	FM	AM
RF Output Power (Watt)	3	1	1	10
# of Channels	1	1	4	3
Antenna Type	Single Conductor with end Resistor	Loop	Single Conductor with end Resistor	Loop
Transmission Mode	Half Duplex	Half Duplex	Half Duplex	Full Duplex
Dual Frequency Repeater	No	No	Yes	Yes
Data Transmission	No	No	Yes	No
Calling	Voice + 1 KHz Tone	Voice	Voice	Voice & Confidence Tone
Portable				
Frequency (KHz)	150-250	100-1,160	290-430	2,500-3,500
# of Channels	1	1	2	3
RF Output Power (Watt)	<1/3	1	1	10
Antenna Type	Ferrite	Loop	Ferrite	Loop
Workable Hours (One Charge)	8	8	8	2
Working Ratio Transmit / Receive + Standby	25%	10%	N/A	N/A
Transmission Mode	Half Duplex	Half Duplex	Half Duplex	Half Duplex
Remote Mike	No	No	Yes	Yes
Calling	Voice	Voice	Voice + Tone (P.T.T.)	Voice

attainable by installation of intermediate components hardwired to the base, for example several base stations could be wired together.

4.3.2 M.S.A. Minephone 1680

Following tests in the U.S. of the Substrata System, a similar system was developed by the USBM and eventually marketed by MSA under the name Minephone 1680. It is a narrowband FM transceiver system, operating with repeaters. Because it is FM, it has excellent signal to noise ratio. Frequency is in the range of 60 KHz to 1,000 KHz, and it uses a loop antenna. A noise operated squelch has been added. To increase the range, the power output of the base station has been increased to 20 watts.

The antennae have been redesigned eliminating the need for tuning. A mobile unit and antenna have been added to the line aimed at vehicular machinery (LHD's, jeeps, trucks, trains, etc.). The vehicular unit is used in conjunction with a special loop antenna of advanced design that produces high magnetic moment. The antenna is enclosed in high strength lexan and is attached to the vehicle via special brackets. The lexan will not break even if severely flexed by impact. M.S.A. also had a vest transceiver design. By placing the radio circuit modules in pockets on the vest, the weight and bulk of the transceiver have been evenly distributed. The loop antenna is sewn into the back of the vest. The pockets are located where medical records show less frequency of injury. Sound is directed towards the ears from epaulet speakers. The design allows the miners to maneuver in tight quarters and perform normal mining tasks without catching the radio on obstructions.

The system can be interfaced with the M.S.A. minephone pagers.

The transmitters are designed with both subaudible (100 Hz) and inband (1,000 Hz) tone oscillators. A subaudible tone is used in the vest transceiver to cause the repeater to switch the message to the pager telephone network. The repeater includes both a noise-operated squelch and a subaudible tone squelch for use in telephone switching. Subaudible tone signalling is useful in identifying "stuck on" transmitters that can block communications. In-band signalling is useful in emergency situations.

The U.S.B.M. design was also taken by a company called Stolar Inc. The Company's aim is to extend the capabilities of the FM system by redesigning the handsets (vest) and also by adding data transmission capabilities to the system. The concepts look very promising and a prototype is expected to come out for test in mid to late 1985.

4.3.3 Nagano Japan Radio Company Limited

In parallel with the work done in South Africa and the U.S.A., Japan has developed its own underground communication system. It was designated by the government for compulsory safety use by all coal mines in Japan and is used in Australia.

This system uses amplitude modulation in the range 150 KHz to 250 KHz. The base station weighs 23 Kg which means that careful planning must be made before installation. The output power is 3 watts with 1 watt audio output.

The base station antenna takes the form of a single conductor cable 3.5 mm^2 with 600v insulation laid in the area where reliable communication is required. The manufacturer recommends that this cable be installed at man height for better access and thus easily be touched by the antenna of the handset. The cable is terminated by a resistor to maintain the impedance and optimize signal strength from the base. Controls on the base station are gain, squelch and call. The call is a level 1 KHz tone which is easily picked up by the handset even when not close to the antenna. The handsets are very small, lightweight (not much bigger than a cigarette pack and easily fits into a pocket) and use a ferrite antenna. It is powered by a 4.8V Ni-Cd battery sufficient to give eight hours of operation at a 25% transmit over receive and idle ratio. The RF output power is less than 300 mW. A new design with high power output (1 watt) and using frequency modulation is expected to be available in September 85.

4.3.4 Plessey Electronics System

Plessey's Figaro System was designed for fire fighting and emergency services and is utilized where other methods have proven ineffective. Such environments include deep basements, tunnels, highrise buildings, subways, ships and other screened areas which normally shield radio waves.

The system works on AM at 2,500 KHz to 3,500 KHz with 3 channels 400 KHz apart. The 3 channels are available both on the base station and the portables. Both units have a

rated RF output power of 10 watts. The audio output is 3 watts on the base and 10 mW into an earphone on the portable. The portable transmission is voice-actuated using a headset with a throat mike. The system uses the base as a repeater transmitting frequency F1 and receiving frequency F2 (F1 smaller than F2) while the portable transmits at F2 and receives at F1. A feature added to the base is that at any time, even when transmitting, it can receive emergency calls from the portable (full-duplex).

The base station antenna is composed of crossed loops which fold into an easy-to-carry package. The plane of the two loops are perpendicular to each other. The portable antenna fits into an apron worn by the personnel. The apron also has a pouch in which the portable radio fits leaving the operator totally handsfree. The system offers portability and ease of installation, two prerequisites when handling emergencies.

The system was tested at several metal mines. Results showed very good coverage with no loss of reception or transmission over the length of the drift (700 metres). Reception was lost when the portable was approximately 25 metres away from a current carrying conductor.

Because the system has no squelch and uses a headset, the operators felt that it was noisy and thus tended to lower the volume when not transmitting. The base station can emit a 'confidence' tone every few seconds and if it is not heard the user knows that he is out of range.

Plessey is developing the system to incorporate a mobile unit for machinery and to change the packaging on the portable to satisfy not only the emergency services requirement, but also production crews. The mobile unit is already under test.

4.3.5 Silec (Division Signalisation Industrielle)

The Silec system is marketed under the label "inductive telephone RTSG581". It has French and German approval for use in underground coal mines and is intrinsically safe. It uses amplitude modulation of the carrier at frequencies between 100 KHz and 1,160 KHz. The RF power output is adjustable .15 watt to 1 watt.

With automatic gain control, the base station front panel has only an on/off switch. It weighs approximately 8.5 Kg and it accepts two types of antenna; the mobile loop antenna designed for a vehicular unit and the fixed loop

antenna for base station applications. The portable unit weighs 1.7 Kg and uses a coil antenna serving as a carrying strap. Ni-Cd batteries powering the portable are rated eight hours for a transmit to receive standby ratio of 10%.

4.3.6 Montan-Forschung

Interest in underground communications in German coal mines has been present for sometime. In early 1970, Bergbau-Forschung (German Mining Research Centre) developed a system which was to provide a totally portable link using small sets. Transmission was effected by coupling into an insulated conductor loop. The system was of FM repeater type with the base station receiving at 430 KHz and transmitting at 290 KHz. The portable units designed by Bergbau-Forschung are intrinsically safe, lightweight and about the size of a walkie talkie.

The base station (ZSE-15) has less than 1 watt RF output. Since it is used as a repeater, it does not need to be manned but a telephone handset is hooked up to the base for anybody who needs to contact a supervisor, loader, etc. Several bases can be hooked together by means of a telephone wire to extend the coverage. The antenna is an insulated copper conductor 3.31 mm^2 (#12 AWG), strung throughout with one end connected to the base and the other end spanning the workings and looping back to the base. The return path can be ground provided a proper resistor is connected at the end of each leg. Branches can run from the antenna into different tunnels and drifts if the impedance is there. At the base, two waveguide ohm meters are used to verify the impedance of the antenna.

The proportions of the antenna legs should be respected to allow good transmission. When ground is used as a return, equal signal strength will exist in each leg provided equal antenna length and equal impedance are present on both sides. The antenna is strung on the back (roof) of the drift with an insulator to avoid inadvertant grounds.

The base is usually installed at a central location underground from which it is easy to fan out with the antenna wire. Five wires are needed to connect the base to a remote console on surface. Two for the send signal, two

for the receive, and one for keying in the push to talk.

The handheld unit (TSE-16) is no bigger than a regular walkie talkie and is very light. A ferrite antenna is incorporated in the casing making it less susceptible to shocks and damages. The unit possesses auto squelch, auto gain control and is useable with a throat mike. There are no switches other than the on/off switch on the unit. At the beginning of a transmission, a high pitched tone is generated when the user presses the PTT switch . When he releases the PTT switch, a lower pitch tone is transmitted. Thus there is no need to develop and learn a communication jargon since the users know when the caller is finished speaking. This could be used as a code call system when voice is not needed. The batteries are designed to last a full shift. The RF output is less than 1 watt.

The mobile unit (MSE-22) is of the same type and size as the hand held unit with the same power output. It was designed to accomodate a foot-activated push-to-talk mike. A remote loudspeaker is usually connected to the unit to amplify the voice signal. The mobile antenna is placed directly on the equipment and if the equipment is electrically powered, the antenna is placed adjacent to the feeder cable. With inductive coupling of the signal into power cables, the caller can be as far as 200 metres away from the antenna and still have perfect communication with other mobiles or the remote console.

The base station, hand held and mobile units come in a variation of housings from the intrinsically safe, explosion proof, to the regular dust proof to suit different applications.

The base station was recently modified to accept two more channels at 120 KHz and 190 KHz dedicated to data. The frequencies were separated to avoid cross talk between data and voice and to allow simultaneous operation of both.

4.4. Installation - Examples

4.4.1 Mine D

The commercial verison of the Substrata System was installed in Mine D a uranium mine. The operators found that the system did indeed provide the portability and range expected. However, the system needed constant tuning. During the tests the system was found to be susceptable to man made noise: neon lights, rectifiers, electric motors,

switch gear, and sometimes cable joints. That, combined with the fact that not everybody was willing to carry extra weight slowly decreased usage and attraction of the system and it is not in service anymore.

Mine D also tested the M.S.A. Minephone 1680 and found that it worked quite well. The signal to noise ratio was good and the coupling antennas worked well but the mobile antenna was thought to be too big. The lack of a handheld unit, (the vest unit was not marketed by M.S.A.), made the system unattractive for multilevel mines where supervisors are on foot. The system was also tested at a multilevel metal mine with a very high sulfide content in the ore. Attenuation of the signal was noted but studies have been made to related it to the sulfides. Again the lack of hand held units was considered a serious disadvantage.

Mine D also installed a Silec System. Technicians from Silec France, were present during installation and they used their expertise to iron out problems encountered at this stage. The system spanned two levels with four base stations, one portable, and one remote control console. Three of the base stations were used as vehicular units.

The system was tested for quality of reception throughout the area involved and wherever poor communication was encountered, the inductive path was analyzed and modified.

In one particular area where communications were considered poor, it was found that the inductively-coupled signal had to travel an excessive distance and losses were significant. To eliminate this long signal path, a 3.31 mm^2 (#12 AWG) wire was pulled through a diamond drill hole and both ends strung parallel to the power carrying cable for approximately 70 metres. This improved the signal greatly and good communication was obtained.

In a haulage area where a trolley line was present over the length of the drift, communications varied from good to none. The variations were abrupt particularly close to a transformer rectifier station which was interrupting the signal. A direct coupling was installed into the trolley line and connected to a 3.31 mm^2 wire which was strung in parallel with the signal carrying cable for

approximately 200 metres. The connection into the trolley line was capacitor-coupled and fuse protected to avoid any danger of raising the voltage of the wire. The result was improved communication all along the haulage way with only minor static created by the trolley.

In a noisy area, it is difficult to hear a call coming in and sometimes the efficiency of the system is affected. The mine decided then to install lights on the base station which flash when a call is coming in.

The system is working successfully and although not of the repeater type, the mine has plans to expand it to include more vehicles.

4.4.2 Mine E

The Nagano System was installed at a multilevel uranium mine. The base station is on surface manned by an employee on light duty. There are ten hand portable units with four, on average, underground at all times, the others being on charge. The portables are used by shifters, jumbo drillers, LHD operators, and maintenance personnel.

The antenna consists of a 3.31 mm^2 (#12 AWG) solid copper conductor extending from the shaft and forming a roughly 2.4-Km circumference loop through the workings and back to the shaft. The antenna was installed so that it can be touched by the antenna from the portable at any point.

The full beat, which extends as far as 500 metres from the antenna is covered by the system, with a minimum reach of approximately 2,100 metres. Using the base station as a relay to initiate conversations between portables, a maximum reach of approximately 1,200 metres from portable to portable was achieved.

Noise problems occur when the induced signal goes through substations or transformer areas. This can be eliminated by by-passing this location using a piece of wire to inductively couple the power cables in and out of the substation.

Connection from the base station down to the working level is through a co-axial cable down the shaft. The cable used is a CTV cable. Enough leakage through the co-axial cable exists so that men can use the portable unit for shaft inspection. Comments from the operators indicate that they feel the CTV cable is not rugged enough for installation in the shaft.

Further development of the system is concentrated on the handsets to increase the output power level as well as adding a remote microphone, selective paging, and LED indicator to attract attention when a call is received.

4.4.3 Mine F

The Montan-Forschung System was installed in a European multilevel metal mine. Access to the mine is through a ramp to a depth of 1,200 metres and men and materials are transported by trucks, loaders, or train. The mine is highly mechanized with approximately 70 pieces of mobile machinery and only 35 miners in the mine per shift. The maintenance crew is based on surface.

For safety, maintenance and repair and optimization reasons the mine decided to install the Montan-Forschung System throughout the mine. The base station is located at the 800 level. The antenna uses ground as a return with multiple branches throughout. As recommended, the two wave guide ohm meters were installed at the base to monitor the antenna impedance. Initially, poor ground prevented achieving 300 ohms and a grounding rod installed in a wet solution had to be used. Periodically the grounds are checked and maintained at the 300 ohm level.

The base station is connected to a remote console located in the central control area on surface manned 24 hours a day.

When a new area is developed the antenna is not extended until communication is lost, thus keeping the labour costs associated with the system to a mimimum. Communication is excellent throughout the mine between mobiles and from mobile to surface.

More than seventy vehicles are equipped with mobile radios and seven hand-held units are used also. Mobile units are on the locomotives which transport the ore out of the mine.

Since the system is a courtesy type system, everyone can hear the conversations. It was a problem at first since everyone wanted to participate and the batteries, rated for one shift under normal usage would last only two hours. Now the novelty has worn off and the batteries last a full shift.

Most of the problems were minor and caused by noise from trolleys and generators through the power supply. Those were filtered out without much difficulty. The system has required no maintenance and the mine has only one spare unit for seventy mobiles. System expansion has no limit in terms of number of units or coverage area since several base stations can be hooked up in series. When the vehicles exit the mine, the communication system switches automatically to VHF taking advantage of free air transmission.

5. DATA COMMUNICATION FOR MINE MONITORING AND CONTROL

5.1 Introduction

Mine monitoring and control systems can increase productivity and improve safety in mines. In this chapter systems are reviewed with attention paid to the effectiveness of the data communication and monitoring control applied.

Various configurations of mine data communication monitoring systems are discussed in terms of system components and system communication formats. Specific characteristics of four commercially-available systems are presented but no detailed discussion of sensor types and final control elements. The types of input and outputs signals required by the mine monitoring systems reviewed.

The reliability of the equipment and installation considerations are of paramount importance. These two are discussed with reference to the technology of the systems as supplied by the vendors and the actual installations in the mines visited. A perspective on future developments by the users is presented.

5.2 Objectives of a Mine Monitoring System

Several mines were visited during the course of the project. Each of these had definite objectives outlined before implementation of their data communication and mine monitoring system. The following is a general summary of objectives.

1. Reduced production and haulage costs.
2. Safety improvement.
3. Improved maintenance and effectiveness of electrical and mechancial hardware.
4. Utilities optimization.
5. Ventilation optimization.
6. Improved fire control.

In general, the overall philosophy was to reduce the cost of production and maintenance by minimizing waste of manpower and

materials. Five of the six mines visited have achieved this. The sixth was in the early stages of implementation savings and savings had not yet been realized.

Four methods these mines are using to reach the six objectives listed above are:

1. Production Schedule Control. This technique requires each piece of production equipment and mobile haulage equipment to be monitored with respect to operating status and position within the mine. The information is communicated to a central surface computer, which compares actual activity within the mine with a preset daily schedule. A central control room operator monitors deviations from the schedule and reacts accordingly by contacting production equipment operators.

2. Stationary Process Equipment Status. This technique requires monitoring of variables associated with electrical and mechanical equipment within the mine on a continual basis. A change in status alerts the central control operator to take immediate remedial action related to either production or maintenance.

3. Ventilation Optimization Monitoring and Control. This technique requires air quality and quantity monitoring and display in a central location accessible by mine supervision. Thus optimized remote control of ventilation doors and fans in relation to mining activity can take place.

4. Fire Control. This technique requires centralized fire detection and subsequent remote control of the ventilation doors, ventilation fans, and mine alarm systems. The capability to shut down electrical power sources must be available. As a result it is possible to contain the fire, provide ventilation where needed and eliminate electrical hazards.

No one mine had incorporated production schedule control, equipment control, ventilation optimization, and fire control into a single system. However, with effective system design this is possible.

A recent report by the United States Bureau of Mines indicates that mining industry needs fall into two priority categories. The first priority is improvement in production, haulage, and maintenance. Second priority improvements are in ventilation, communication, fire monitoring, and personnel. Observations made at the mines visited indicate that these needs are being addressed. When data communication and mine monitoring systems are carefully implemented they are met.

5.3 Mine Data Communication and Monitoring

A data communication and monitoring system centralizes the presentation of process graphics, status and alarm conditions of all associated operating and process equipment, histories of process events, equipment performance trends and maintenance information. The system also provides centralized control of the process. Centralized process monitoring and control systems have been used successfully in surface processing plants for at least three decades. It is proven technology which can be readily applied to the underground environment.

Initially, data communication and monitoring systems were centralized. In other words there was a large central computer to which all sensed and controlled points were wired separately. The central computer was expected not only to provide a monitoring/alarming and control function, but also a management information system function. In the multi-level mining environment hardwiring all sensed points and control outputs separately to a central location is impractical. This led to the evolution of a centralized system having a main host computer with a single trunk or data highway carrying multiplexed data.

A single multi-conductor trunk cable is wired to each sensor throughout the mine. The need for separate wire connections between each sensor or final control element and the host computer is eliminated. Time multiplexed (Refer to Chapter 3 - Multiplex Systems) sensed and control binary data is communicated along the trunk cable.

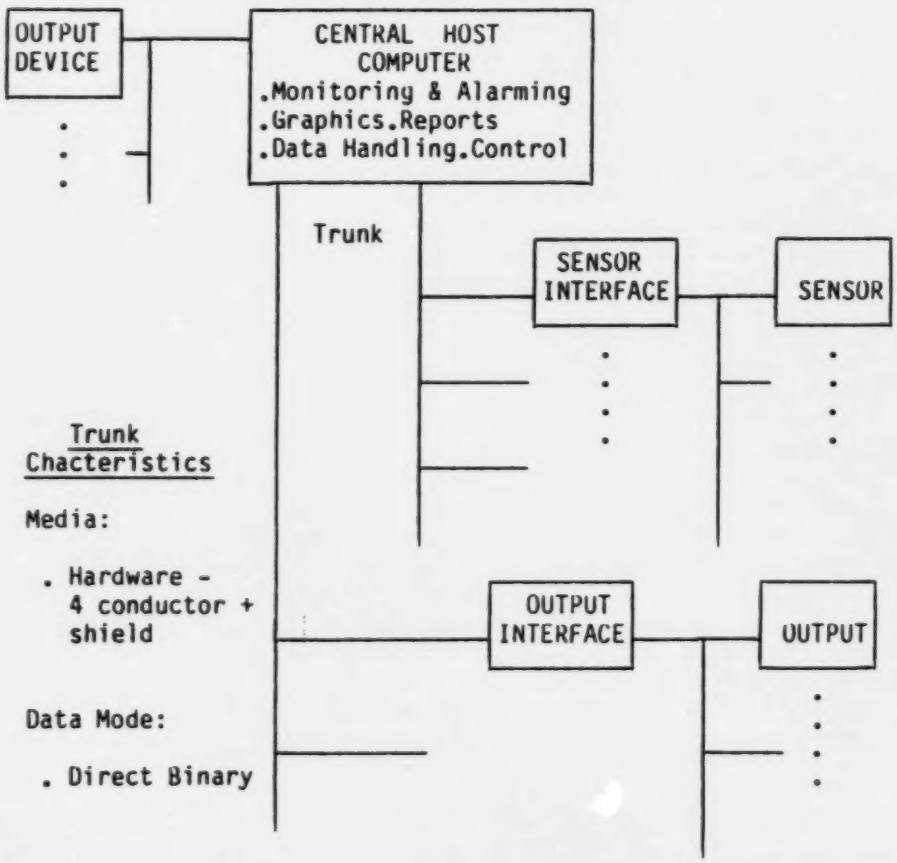
The next step in the evolution of the mine monitoring system was to use a distributed configuration. Distributed control systems are characterized by multiple computers linked by data communication highways which handle direct binary data or

a synchronous data. In the future, distributed systems will be enhanced by fiberoptic technology which will act as a high speed and volume data highway to which an infinite number of microprocessor based outstations may be attached.

State-of-the-art centralized mine monitoring and control systems depend on a single central or host computer to carry out all monitoring and control information handling, as well as graphic presentation and management information system reporting. (See Figure 5.1)

Figure 5.1

COMPUTERIZED MINE MONITORING SYSTEM



Information is gathered from sensors and dispatched to outputs by means of a specialized trunk cable to which each sensor and output device is interfaced.

Centralized systems are subject to total system collapse as a result of either a hardware or software failure within the central processor or a failure of the trunk cable. Failure of the host computer can be minimized by adding a redundant host. A redundant trunk would also have to be engineered into the system to lessen the effect of a trunk failure. Achieving failsafe conditions within the process upon a system crash is limited because the 'non intelligent' sensor and output interface logic cannot be programmed to sense changes in the process and bring the control elements to a failsafe position. This is one of the major disadvantages of a centralized system configuration.

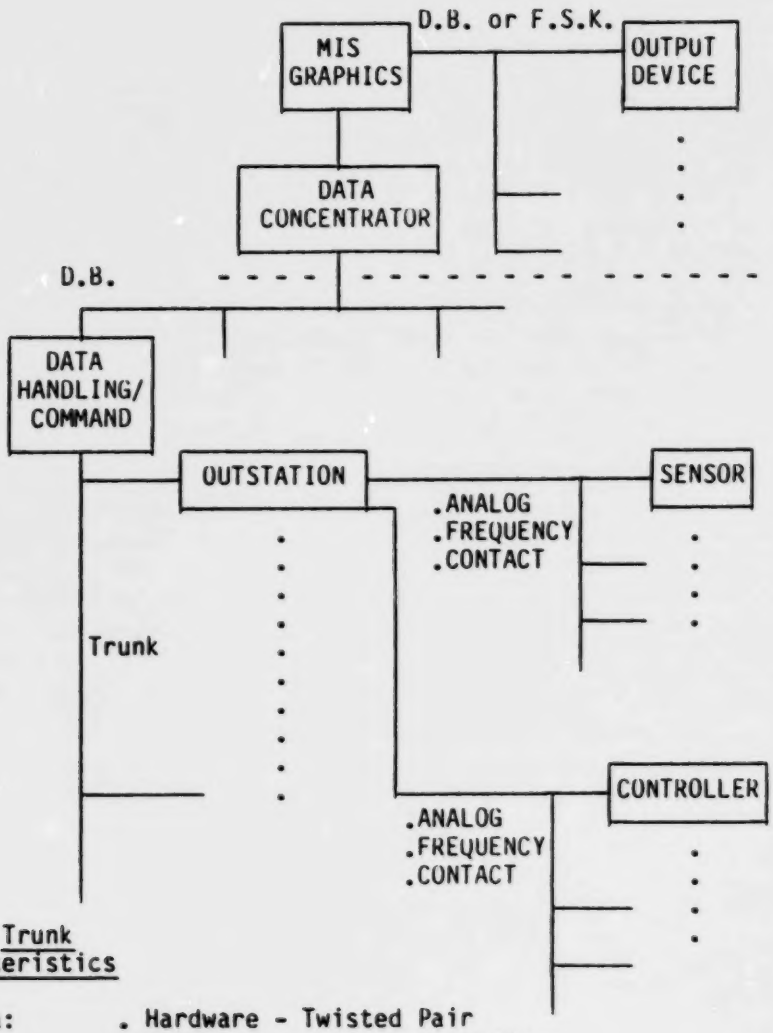
A distributed system configuration (Figure 5.2) can consist of microcomputers, minicomputers, and large mainframe computers. There can be three layers of computing power between the sensor or the final control element and the host computer. Directly associated with the sensor and the output control element is the outstation. Outstations are designed using smart microprocessor based logic and thereby can easily be programmed to control the process to a failsafe state without input from a supervisory computer. The next layer of supervisory computing power carries out the data handling and commanding of the outstations. Relevent information is then gathered from the data handling command computers by a data concentrator which funnels this data into the management information system/process graphics host computer.

Communication between the outstations and the data handling command computers can take place over a single shielded twisted pair or by radio transmission. The data transmission mode in this case is asynchronous, FSK, at speeds of 300 to 2400 baud. Communication between the data handling/command computers, the data concentrators, and the host computers is usually at high speed in direct binary on a data bus. Line length limits where data bus type communication is possible but where the second and third levels of computing power are in close physical proximity data bus links are used.

Mine data communication and monitoring systems have evolved from a centralized configuration to a distributed configuration in step with this evolution in the technology of surface installations. A distributed system is clearly most advantageous for the following reasons:

Figure 5.2

DISTRIBUTED SYSTEMS



Trunk Chacteristics

Media: . Hardware - Twisted Pair
. Medium Frequency F.M. Radio

Data Mode: . FSK
. DB

D.B. - Direct Binary
F.S.K. - Frequency Shift Keying

i) Micro-processor based computing power is provided at the outstations.

ii) Expandability is facilitated by the ability to daisy chain data handling/command computers and outstations together on data highways or synchronous trunks.

iii) A total system crash is generally avoided because each computer-based component can be programmed to operate independently in a failure situation.

iv) A failsafe mode of operation can be assumed by the outstations should the supervisory levels of computing power be lost.

v) The central or host computer need not be overloaded with both management information system and monitoring and control responsibilities.

vi) Redundant backup for the host computer or the main trunk cable is not necessary.

As a result of the above advantages and the reduced cost of purchasing microprocessor-based hardware, mine data communication and monitoring systems which have a distributed configuration are becoming state-of-the-art.

5.4 Commercially Available Systems

System suppliers can provide all the computing, telemetry, hardcopy, and input/output interface hardware required to make up a mine data communication and monitoring system. Various sensors and final control elements are generally purchased from separate vendors. What follows is a synopsis of the technical characteristics of each commercially-available mine monitoring system reviewed. (Refer to Table 5.1 for Systems Summary)

5.4.1 Conspec Controls Incorporated

Conspec's Senturion Series 200 monitoring system consists of a central computer that has associated with it a CRT display keyboard, two printers, and one or more data concentrators. This system is capable of monitoring four trunk lines. Each trunk line is capable of carrying 128 input or output locations. At each input or output location there is an addressable access or card which converts the sensor signal to binary or converts a binary command to analogue or a digital output.

The trunk cable is a customized four-conductor cable. Two conductors are used to provide 30 volts of DC power and the remaining two carry the signal. Maximum length of each trunk is 1,400 metres. Data is transmitted at 600 baud and is in a direct binary format. When it is not economically feasible to run a trunk line to an accessor, sensor information can be transmitted to the trunk using long distance accessors which are interconnected with single twisted pair telephone line.

A software package provided with the system has been developed by Conspec and is user friendly. The technician responsible for the system can quickly learn how to change alarm thresholds and to set high and low control limits as well as control setpoints. Alarm reports as well as end of shift reports can easily be designed and outputted.

Accessors are designed to handle the following inputs: 420 milliamps, 0-5 volts, 0-1 milliamp, resistance, RTd, and contact closure. (Reference - USBM Report)

5.4.2 Outokumpu Instruments Canada Limited

The Outokumpu mine monitoring system consists of a host computer, which is the third level of computing power, and can provide a management information system as well as process control graphics. The second level of computing power is provided by a central communication terminal. The number of central communication terminals allowable in the system is unlimited. Each central communication terminal is capable of monitoring and commanding four remote control terminals or outstations. The remote control terminals are smart microprocessor-based devices. Each outstation is capable of accepting four analogue inputs and sixteen digital control outputs. Data transmission is accomplished over shielded twisted pair telephone line in serial RS232 FSK format at 300 baud. Each message has a data blocklink of up to sixteen bytes and as many as twenty-four check bits.

Identical printed circuit boards are used in the remote control terminals and in the central communication terminal. As a result system maintenance is readily attained. The executive programs resident in the outstations and in the central communication terminal are provided by Outokumpu on PROM'S. The system electronics is manufactured by SLO Electronics in Finland, and marketed by Outokumpu.

The host computer system provides user friendly software to allow the operator to implement control monitoring and optimization strategies. The host or MIS computer system can be provided either by Outokumpu or SLO Electronics with selection depending on the application.

5.4.3 Gould

The Gould Mine monitoring and control system is based on a network of programmable logic controllers (PLC's) made by Modicon. Modicon is now a wholly owned subsidiary of Gould. The outstations or first level of control computer logic are Micro 84 PLC's. The second level or data handling and command logic is realized by using Modicon 584 PLC's. The 584 PLC's gather data from the outstations and pass commands from the operator's consoles to the outstations. The data handling command 584 PLC's route data to a data concentrator, which again is a 584 PLC, that is capable of driving chart recorder inputs, doing historical trending, and carrying out system diagnotics. At the control console the operator views process status and takes control action. The console contains two Modvue screens which are touch sensitive. Therefore there is no need for a keyboard. All control actions are taken by touching the appropriate location on the displayed process graphic. Therefore from the console the operator is capable of stopping or starting conveyors, selecting motor currents, and varying the speed of bin feeders, as well as monitoring these operations.

The communication of data takes place over the trunk line which is a shielded twisted pair. This "Mod Bus" interconnects the 584 data handling/command PLC's with the micro 84 outstations. Data transmission is of the asynchronous FSK type at 2400 baud. Each 584 is capable of servicing 128 micro 84 outstations on its trunk. There is no limit to the number of 584s that can be linked together to form a system. Each micro 84 is capable of accepting one analogue input, sixteen digital inputs, and generating one analogue output and sixteen digital outputs.

Basic programming capability is required to coordinate the movement of data throughout a Gould system. Modvue graphics are generated using menu-driven software.

5.4.4 Montan-Forschung

The Montan-Forschung SMP-30 systems have been designed for monitoring and control applications in coal and non-metal

outstations linked to a data handling/command computer which can through a data concentrator feed data to a large host computer. For smaller systems where a large mainframe cannot be justified a Victor personal computer may be used to provide third level computing power. Hardcopy output devices can be readily linked to the system.

Data communication between the data handling/command computer and the outstations is in an asynchronous FSK mode at 600 baud. Data is transmitted using two medium frequency carrier frequencies. The transmitting carrier is 120 KHz while the receiving carrier is 190 KHz. The trunk line is a two-conductor twisted shielded cable. Each outstation is capable of monitoring 72 digital inputs and 72 analogue inputs if they are of a frequency type. The outstation is also capable of generating 42 digital outputs as well as one analogue output with 8 bit digital to analogue resolution. As well as this the outstation is capable of linking to intelligent remote digital input units along its own trunk line. Up to 70 of these units can be added, each monitoring 12 digital inputs. An additional feature of the Montan system is that the digital sensing stations can be linked to the outstation by medium frequency FM radio transmission making them suitable for the monitoring of mobile mining and haulage equipment. In this case the shielded twisted pair is replaced by a medium frequency radio link. All other characteristics of the data transmission remain the same. Refer to Chapter IV for a detailed analysis of Medium Frequency Systems including the Montan System.

Additional data handling/command computers and trunk lines can be added to meet the demands of the system. Data from these units is transmitted in binary format at 9600 baud to the data concentrator for funnelling into the mainframe computer system.

5.4.5 Modudata Systems Limited

The Modudata Termiplex 1100 System is a data multiplexing system which can monitor status of and provide control to remote locations over a single twisted pair. It will operate in a party line or loop configuration allowing signals to be received at or transmitted from any location. This system, unlike the four systems described above is not microprocessor based. The Termiplex 1100 consists of multiplex logic capable of communicating by means of addressed serial pulse train data at speeds from 15 to 9600 baud. There is no intelligence or computing power associated with this system and as a result the capability to provide a management information system, process graphics, data handling/command computer power and intelligent

failsafe outstations do not exist. However, the Termiplex 1100 can act as a configuration of 'dumb' outstations for a data handling/command computer.

The master station can handle one trunk. A maximum of 32 outstations can reside on a trunk each capable of multiplexing 16 analogue or digital inputs and 16 analogue or digital outputs. The method of data transmission used is line keying. Voltage or current are keyed on and off along the transmission line to generate serial data in a Time Division Multiplexing non-return-to-zero mode. It is conceivable that a number of master stations and trunks could be coordinated by a single data handling/command computer.

Termiplex 1100 series systems can be designed to stand alone as data communication and monitoring systems. In one of the mines visited this was the case. Modudata provides a series of annunciator panels and control consoles to meet this need.

5.4.6 Mine Data Communications and Monitoring Systems Summary

A summary of the Mine Data Communications and Monitoring systems reviewed is given in Table 5.1.

5.5 Sensors and Final Control Elements

The selection of sensors and final control elements is as difficult and important as the selection of the mine monitoring system itself. It was not the intent of this project to review sensors and final control elements. A detailed study would be required to define and describe the characteristics of the various sensors available to monitor variables in the mining environment. It is equally difficult to assess final control elements. Reference is made to environmental sensors in the US Bureau of Mine Report IC8955. Only sensor output signals and final control element input signals will be discussed in this report.

Generally, sensor inputs such as changing resistance, pressure, RTD, current (4-20 milliamps, 5-10 milliamps), voltage, varying frequency, and contact closure, will be accepted by all mine monitoring systems. System outputs typically include: current, voltage, and contact closure. The output signal from any sensor can be converted into a form which is measureable by a mine monitoring system. Similarly, the output of a mine

TABLE 5.1

MINE DATA COMMUNICATION AND MONITORING SYSTEM SUMMARY

	Conspec	Outokumpu	Gould	Montan	Modudata
Current Installations:					
Coal Mining	Yes	No	No	Yes	No
Metal-Nonmetal Mining..	Yes	Yes	Yes	Yes	Yes
Specifications:					
Data Transmission	DB	FSK	FSK	FSK	LK
Cable (# of conductors)	4+S	2+S	2+S	2+S or F.M. (Med.)Freq.	2+S
Power Requirements, V:					
Ac	110	110	110	110	110
Dc	12	24	-	-	-
Trunks	4	Unlimited	Unlimited	Unlimited	
Outstations per Trunk ...	128	32	128	3	32
Inputs per Outstation .	17	20	17	72	16
Analogue	1 (16 BIT)	4	1	72 (Freq.)	16
Digital	16 (1 BIT)	16	16	72	16
Outputs per Outstations	1	16	17	45	16
Analogue	NA	NA	1	1	16
Digital	1 (1 BIT)	16	16	42	16
Transmission Distance .	4000 Ft.	>6 Miles	>6 Miles	>6 Miles	>6 Miles
Central Control Console:					
Process Graphics	Yes	Yes	Yes	Yes	No
Management Information System	Yes	Yes	Yes	Yes	No
Process Control	Yes	Yes	Yes	Yes	Yes
Applications:					
Production Improvement	Yes	Yes	Yes	Yes	Yes
Belt Monitoring Contr.	No	No	Yes	Yes	Yes
Vent.Monitor& Control	Yes	Yes	Yes	Yes	Yes
Mobile Equip.Monitor.	No	No	Yes	Yes	No
Elect.Equip.Monitr.	Yes	Yes	Yes	Yes	Yes
Ground Control	No	No	No	No	No

Reference - USBM Report

D B - Direct Binary

monitoring and control system can be converted to a form which will operate a final control element. Sensors must be chosen carefully so that accurate measurement of the process variable takes place. Most sensor development has occurred in the area of mine ventilation. Devices exist which provide acceptable air volume and air quality measurement. However sensors capable of measuring ground control and production variables are in the development stage. Concentrated effort in designing a broad range of sensors for the mining environment is required.

5.6 Reliability of Equipment

Reliability of mine data communication and monitoring systems can be ensured by careful design of the installation. Most system failures result from physical damage to the equipment or failure of the electrical power source. Failure of the electronics will be infrequent if they are kept in the specified environment. Therefore it is important in the design to ensure that the control electronics placed underground are housed in enclosures which are corrosion resistant, dust proof and moisture proof. The second system component prone to physical damage is the trunk conductor. The least expensive and most easily repaired trunk conductor should be selected. During installation extreme care must be taken to locate the conductor so that the possibility of damage by mobile equipment is minimized . Unreliability as a result of power source failure can be overcome by battery backup or UPS systems in the design.

5.7 Mine Data Communication and Monitoring Systems Visited

5.7.1 Mine G

The objectives of a mine-wide monitoring system are to reduce production and development losses, lower maintenance and operating costs and provide a system which is capable of continuously monitoring equipment status from a central location.

The scope of the remote monitoring and control system includes the status of power distribution switch gear, haulage rectifiers, pumps, ventilation, air compressors, and chilled water system. Analogue information is gathered from remote points indicating airflow, carbon monoxide levels, compressed air pressure, and waterflows. Over 300 individual pieces of equipment are monitored from 26 remote locations. The central control room operator monitors the status of the above equipment on a mimic or process display board in the central control room. If necessary he takes immediate remedial action on a change in process variable status. He does this by

changing the state of the equipment from his control panel or by communicating verbal directives through the mine-wide voice communication dispatch centre which is located in the central controlroom area.

The benefits provided by the mine monitoring system include:

(a) The reduction of production and development losses due to the unexpected failure of vital support systems, such as mine compressed air, mine dewatering and the mine electrical power.

(b) Improved maintenance response.

(c) Fire control.

(d) Improved personnel safety.

Future development of this mine monitoring system will include the introduction of a main frame computer which can provide a management information system and maintenance trend reporting.

The successful implementation of the mine monitoring system was due to the commitment of management and the dedication of the General Foreman and Project Engineer, who installed the system, and are continuing to help it evolve.

5.7.2 Mine H

The objective of the mine monitoring system is to optimize the transportation scheduling of ore from the drawpoints to the chutes. Trackless mobile equipment such as trucks and scooptrams are used in this environment. The drift and travelways are narrow and do not allow for passing. Therefore traffic must be controlled so that waiting time is minimized. Each piece of production and mobile equipment transmits its location, operating mode, and ore type to the central controlroom. The host computer compares equipment status and position with the daily production schedule and alerts the central control operator to scheduling problems on a mine wide process control graphic. The operator then determines whether it is a maintenance, production, or traffic problem and takes immediate remedial action.

The mobile haulage equipment and production equipment use medium frequency, frequency modulated radio telemetry to communciate with the mine monitoring system. The same system provides voice communication with each piece of

equipment. The observed benefits of this mine monitoring and control system include:

(a) Reduced manpower - As a result of the combined effect of the mine monitoring system, increased mechanization, and mine-wide voice communication the workforce in the mine has been reduced from 300 people to 70 people, without production loss.

(b) Improved equipment utilization - As a result of effective traffic control, the number of pieces of mobile equipment has been reduced.

(c) Improved grade control. Dilution can be controlled by the carefully scheduled haulage of different grades of ore.

Future plans at this mine include further historical analysis. This statistical analysis will be used to optimize manpower and the quantity of production equipment.

5.7.3 Mine I

Mine I's objectives for its mine monitoring and control system are to provide an optimum supply of air to all working areas, to centralize the control of the mine ventilation system, to continuously monitor quantity and quality of mine air and to predict the possible changes in ventilation caused by stoping or blasting.

Mine supervision can select several ventilation patterns from a surface control console. The host computer automatically operates ventilation doors and controls airflows relative to a selected ventilation model. This model has been designed to pertain to a particular type of mining activity. Ventilation doors are activated manually to allow the passage of mine mobile equipment. However, the computer returns the door to its preset position. Operation of each ventilation door is possible from the surface control console as well. In the event of a fire, doors can be closed or opened to contain the affected area.

The mine monitoring and control system has provided the following benefits:

(a) 33% reduction in heating energy for ventilation air.

(b) 25% reduction in total energy for main fans.

5.7.4 Mine K

Mine K's largest area of concern was the lack of ability to monitor the status of underground equipment in remote locations. There was means of monitoring environmental conditions, that is, air quality and quantity in a mine where extensive diesel-powered equipment was being used. It was also necessary to know the status of fire suppression systems from a surface location.

Implementation of the system provided monitoring of conveyor belts, crushers, mine air fans, heating plants, mine dewatering pumps, power distribution systems, ventilation doors, airflows, and fire suppression systems.

Central control and reporting locations are provided in the mine supervisory area on surface. Here CRT's and printers provide status and alarm information on all areas monitored in a variety of reports. The system will be expanded to include more extensive control of underground equipment, as well as automatic control of utilities such as power and ventilation.

The benefits apparently include:

(a) Improved maintenance response to equipment failure.

(b) Improved fire control.

(c) Reduced ventilation energy costs.

(d) Reduced power costs.

5.7.5 Mine L

Mine L is a multi-level mine which uses a simple data multiplexing system to continuously monitor power, pumps, ventilation, heating, cooling, return air, sewage treatment, fire detection and hot water heating. Monitoring the dewatering system and the ventilation system are prime concerns at this mine. The multiplexing system enables an operator on surface to tell if pumps are running, to switch pumps on or off, to change the sequence of operation of pumps, to monitor pump power, to control major ventilation fans and to monitor machine vibration. Similarly, production equipment such as conveyors is monitored and controlled.

The benefits provided by this mine data communication and monitoring system are as follows:

(a) Reduction in electrical maintenance personnel required.

(b) Elimination of unnecessary service calls.

(c) Improved ability to handle emergency situations such as fire.

(d) More effective maintenance planning.

(e) The ability to monitor and control process variables at a shutdown mine from a remote location, thereby reducing the manpower involved.

In the future the owner of Mine E sees more extensive use of similar systems in his other mines and integration into central computer systems is possible.

5.7.6 Mine M

Mine M, a non-metal mine, is in the process of implementing their mine monitoring and control system. They have no actual proof of the benefits, while it is important to review the objectives outlined for the system which are:

(a) Provide operations and maintenance personnel with up-to-date information on the status of equipment used in the mining operation.

(b) Improve the coordination of manpower and equipment.

(c) Improve maintenance response in the face of equipment failure.

(d) Provide the underground operator with a centralized control of operating equipment.

(e) Provide operating and maintenance report generation and historical trending.

Implementation of the system is being carried out in a three step process. The first step is to provide annunciation and control. The second step will be to provide report generation, the third step is to provide historic trending.

6. REQUIREMENTS FOR SUCCESSFUL IMPLEMENTATION

6.1 Introduction

Prior to the selection of a Mine Data Communication Monitoring System or a Mine Voice Communication System the philosophy of the system must be defined, and commitment to that philosophy clearly demonstrated by management.
Overall, it is the intent of Mine Data Communication Monitoring Systems and Voice Communication Systems to:

(i) improve productivity by either reducing the workforce or increasing output.

(ii) improve equipment availability by increasing maintenance response to problem areas.

(iii) to improve safety by being continually aware of human and equipment activity in potentially hazardous areas.

Implementation of an effective Mine Data Communication and Monitoring System or a Mine Voice Communication System requires i) an effective human and technical resource organization for implementation, ii) the objective of the system, to be sold to mine personnel, iii) proper equipment to be selected, iv) an installation engineered for troublefree service.

6.2 Mine Data Communication and Monitoring Systems

6.2.1 Equipment Selection

It has been observed that all apparently futuristic ideas related to Mine Data Communication Monitoring Systems or Mine Voice Communication Systems have either been successfully implemented or are well on the way to application.

When selecting Mine Data Communication System hardware the following criteria are suggested:

(a) Price and delivery of equipment and software.

(b) The vendors support for both hardware and software.

(c) Suitability of hardware for the mining environment.

(d) Simplicity of the system electronic components and the level of troubleshooting skills required to maintain the system.

(e) The type of trunk cable necessary.

(f) System configuration - centralized type or distributed type.

(g) Expandability in terms of hardware and software.

(h) The need to monitor mobile equipment or simple stationary equipment.

For ease of maintenance, the hardware selected, particularly for the outstations, should be of an optimized modular design. Such a design requires that the field technician need only understand the overall system flow. This will allow him to check power supplies, check for the transmission of data between the outstations and the data handler and interchange modules with confidence. If numerous duplicate outstations are installed the field technician can interchange modules from one outstation to another to find the fault. In several installations, both the data handling/command computer and the outstation have the same architecture and modules. Troubleshooting at both the first and second level of computing power is facilitated.

In terms of the outstations an important consideration is the type of inputs or outputs both digital and analogue accepted. Full isolation of input and output and analogue and digital is preferable.

Both centralized and distributed type Mine Monitoring Systems are available from vendors. The distributed system appears to be more popular because it is more flexible, more expandable, and permits failsafe operation. Any one station within a distributed system can operate independently in the case of failure. This minimizes the chance of a catastrophic collapse of the system. Another advantage of the distributed system is that it does not require a single computer to do data handling as well as process control.

Data transmission using an FSK format over a shielded twisted pair or telephone trunk line was the more prevalent mode used in the Mine Monitoring Systems observed. The advantages of using a shielded twisted pair cable as the trunk include:

(a) Reduced material costs.

(b) Reduced installation costs.

(c) Ease of repair.

One disadvantage of using a single shielded pair for transmission is that the rate of transmission of data is slow, with the maximum speed in the order of 2400 baud, and typical speeds in the order of 600 baud. The number of outstations per trunk is limited by the speed of data transmisison. Mine Monitoring Systems that use a custom trunk cable are able to use the direct binary mode of data communication. As a result, more outstations can be tied to a single trunk. However, the cost of a custom trunk cable is approximately twice that of a shielded twisted pair.

If mobile haulage equipment requires monitoring, then the mode of data transmission must be radio. The most successful installation observed made use of medium frequency, FM transmission. The data transmission mode was FSK at 600 baud. The outstation relayed information to a base station which then transferred this information to the data handling/command computer via shielded twisted pair.

In any Mine Monitoring System, consideration should be given to expandability. That is, how easily additional trunks or outstations can be added to the system without generating excessive additional cost and programming time. Expansion is most easily accomplished in distributed systems where data handling/command computers can be daisy-chained to the existing network.

6.2.2 Software Selection

Selecting a system based on its software capabilities and characteristics is as important as selection of hardware. One must consider whether the programming required is in a basic language, or whether all programming is package menu driven software, supplied by the vendor. The system software should provide acceptable graphics capability, report generation capability, and the ability to handshake with a host computer.

Basic Software

Choosing a system that requires basic programming assumes that the organization has in-house computer programming skills. Basic programming can be done by engineering level people, but it is more effectively done by trained programmers. The advantages of a system requiring basic programming are:

(a) The mine is in control of its own software system.

(b) An in-house software package has more flexibility in change response to a changing process.

(c) Dependence upon the supplier to commission the software system is removed.

(d) Supplier software support is not required.

However, purchasing a system that requires basic programming has the following disadvantages:

(1) In-house programming skills are required therefore increasing organizational overhead.

(2) More in-house time is required to develop software.

Menu-Driven Software

Menu-driven software packages have the following advantages:

(a) Packaged software comes with the hardware system ready for the operator to use.

(b) Internal programming support is unncessary.

The disadvantages involved in purchasing packaged software from a supplier include:

(1) The Mine Monitoring System is subject to inflexibility of the software architecture designed by the supplier.

(2) System upgrades or changes require the suppliers' programmers and therefore additional external expense.

(3) The mine must rely on the suppliers software support.

(4) The supplier's software support staff must be available for system commissioning.

6.3 Mine-wide Voice Communication Systems

6.3.1 Equipment Selection

Mine wide voice communication systems can be of hardwired design using either commercially available intercom type systems or a variety of telephone networks. These systems have been the standard for underground communication for many years. However, within the last 10 to 15 years, radio frequency communication for the mining environment has been developing. Today it remains in an evolutionary phase. Even so, during the course of the project radio frequency systems which meet the majority of requirements for mine wide voice communication were discovered.

When selecting Mine wide voice communication hardware the following criteria are suggested:

(a) The feasibility of a hardwired system versus a radio frequency system.

(b) The price and delivery of the equipment.

(c) The technical support provided by the vendor parts and service.

(d) Suitability of the portable, mobile, and base station hardware for the mining environment.

(e) Maintainability of the system components.

(f) The capability of applying the hardware directly without modification.

(g) The portability of the personal walkie-talkies.

(h) The adaptability of mobile units and antennas.

(i) The base antenna or hardwire interconnect configuration.

(j) The inhouse technical skills available.

The trend today in the area of underground voice communication is away from the hardwired systems to radio frequency systems. The reason for this is that hardwired systems are hardware and maintenance intensive as well as expensive to install. However, there are occasions when the choice of a hardwired system is economically feasible.

Within the field of underground radio frequency communication a rapid evolution is taking place. Initially the prime concern was to find the most effective frequency for transmission of a signal. It was found that longwave or medium frequencies (100 KHz to 500 KHz) attenuated less over extensive antenna configurations. Shortwave or high frequencies (2 mHz or greater) had a better signal to noise ratio but because of higher attenuation were best for short distance transmission.

The next area of concern was the type of modulation to be used. It was found that an amplitude modulated signal was subject to intrusion of excessive electromagnetic noise whereas frequency modulation virtually eliminates this problem.

The antenna configuration design is an important variable in determining the effectiveness of the system. With medium frequency communication transmission is aided by signal induction into existing piping or electrical cables. However, if the legs of the antenna structure are not matched impedances within the system, standing waves will form and dead spots may result. The standing wave phenomena can be avoided by terminating each antenna leg with the correct impedance. For high frequency systems standard rubber ducky or slot antennas are used.

The antenna conductor construction must be considered. Today's radio frequency systems are moving away from special conductors such as co-axial cable to standard 10 to 14 gauge electrical wire because of the lower cost of material and installation as well as ease of maintenance. It is important to note that the conductor must be placed the specified distances from the walls of the drift and power cables to avoid signal absorption and electromagnetic interference.

In summary, the optimum mine wide voice communication system should have the following characteristics:

(i) Have a medium frequency, frequency modulated mode of transmission.

(ii) Transmit with power below 1 watt.

(iii) Have a matched antenna configuration.

(iv) Be capable of both mobile and personal use.

(v) Make use of an inexpensive easily-installed antenna conductor.

(vi) Be capable of inducing radio transmission onto existing piping and electrical structures.

6.4 Organization for Implementation

The first and most important step in implementation of a mine data communication monitoring or mine voice communicaion system is the organization of human resources to carry out the project. This organization must be capable of selling the concept, engineering the system, supporting the system after installation, and ensuring that the system evolves to meet the future needs of the mine. Once the organization is set, the concept of the system must be sold to all individuals at the mine, from the Mine Superintendent to the ditch cleaner. Without full commitment the full potential of the system cannot be realized.

Typical organizations for implementation at the mines visited included the following characteristics:

(a) An Automation/Electrical Engineer working at an equivalent level to the Mine Engineer.

(b) Programming capability reporting to the Automation Engineer.

(c) Some design drafting capability reporting to the Automation Engineer.

(d) An Electrical Foreman or General Foreman responsible for the maintenance workforce, working in conjunction with the Automation Engineer to install and support the system.

In summary, each mine has formed a multilayered group which has implemented and supports the system. This is the key to having a successful system.

Lastly, it is important to provide positive reinforcement of the fact that the voice or data communication system is generating the benefits anticipated. This can be done by having the users of the systems make a daily record of events which demonstrate a reduction in manpower and materials wastage or improved safety. The continual recognition of the benefits of the system will ensure its evolution and continuing reduction in operating costs.

7. PROPOSAL FOR FIELD INSTALLATION AT RUTTAN MINE

7.1 General

The selection of a radio communication system for underground use is influenced by several site-specific factors. In the case of Sheritt-Gordon's Ruttan Mine near Leaf Rapids, Manitoba, these factors include:

- Geographically isolated minesite - being located several hundred kilometers north of Winnipeg can limit access to expertise in electronics; furthermore, the size of the Ruttan operation cannot justify technical backup on a full-time basis. The system must be especially rugged and as maintenance-free as possible.

- Nature of the orebody - the Ruttan Mine consists of rather complex, steeply dipping ore lenses extending several hundred metres in depth. The communication system must lend itself to operating in a multiple heading, multi-level mine. The system must also operate within a poly-metallic sulphide orebody with conductive, radiowave absorptive properties.

- Nature of the mining operation - Ruttan is a highly mechanised modern 'hardrock' mine with both shaft and ramp access producing over 5000 tons/day. In addition to fixed facilities such as underground garages, crushers, rockbreakers and conveyors, there are numerous items of mobile equipment including LHD's, trucks, jumbos, jeeps, I.T.H. drills, ANFO loaders and other service vehicles. Although many areas of the mine have electrical power cables installed (eg. for auxiliary fans and other electric equipment), some areas are without cables which might propagate radio signals.

- Existing Communications Systems - Ruttan's primary communication systems consist of a PBX telephone system and MSA Minephone intercom-type system and, for shaft communication, a standard bell signalling system.

  The MSA system acts as a back-up and supplement to the conventional phone system but requires considerable maintenance and does not provide communication to mobile units or to the work faces. A mine radio system could eliminate the need to install MSA phones as new mining blocks are developed and perhaps supplant existing MSA phones.

The shaft bell system performs adequately, however it is recognized that 2-way voice communication with the hoistman from within the cage and especially from the top of the cage and skips during shaft inspection would enhance safety and efficiency.

- Expansion of mine - a mine radio system should be readily expandable as the mine develops. Since Ruttan is nearing completion of the "Upper Mine", the selected radio system must be able to accommodate expansion inexpensively as mining of the"Lower Mine" commences. A further factor is the time frame ; the life of the "Lower Mine" is expected to be in the range of five years therefore rapid deployment and payback is necessary.

- Electric blasting hazards - Ruttan's blasting practices include bulk blasts using electric detonators for initiation and a centralized blasting system. The use of radio transmitters with a mine-wide grid of electric blasting cable is of concern to mine operators. While practices can be adapted to permit the use of higher-powered radio transmitters underground within regulations (Manitoba Mines Act. Reg. 254/73 Sect. 7.56), special testing and practices would be unnecessary for mobile transmitters of less than 1 watt effective radiating power. A radio system of less than 1 watt E.R.P. having explosion-proof, intrisically safe design (approved for use in fiery coal mines) would have an unquestionable level of safety for use in Canadian mines.

7.2 Recommended System(s)

In consideration of Ruttan Mine's situation and communication requirements, a hybrid system is required. The first part would be a shaft radio communication system. It is strongly recommended that this be maintained as a separate and restricted access system. The second part would be a mine-wide radio system for general communication including vehicular units as well as portable personal units for supervision and miners in isolated areas.

7.2.1 Shaft Radio System

There are a number of shaft radio systems commercially available that would perform adequately at Ruttan Mine therefore no particular brand is endorsed here. However, in consideration of the shaft depth (910 m) and compartment configuration, it is felt that a system that induces the radio signal onto the hoisting cable would be most practical and would abviate the installation and maintenance of special

cables in the shaft. The FEMCO shaft radio is one such system which has been installed and operated successfully in several Canadian mines. It is suggested that Sheritt Gordon Ltd. solicit competitive bids from several manufacturers (see Appendix A). Specifications should permit direct voice communication and 'bell' signalling between cagetender (even while inside moving cage) and hoistman; extensions would allow the system to be used during shaft inspections (with skip compartment on separate frequency). The estimated cost of the shaft system is shown below; note that this does not represent a design demonstration but a complete practical working system.

Table 7.1.

Cost Estimate of Shaft Radio System

Recommended System:	FEMCO or equivalent; voice and "bell" signal capability; base unit; units for cage and skip; extensions to facilitate shaft inspection	
Approximate system cost		$15,000
Approximate installation cost (labour)		2,000
TOTAL COST		$17,000

7.2.2 Mine-wide Radio System

Given the extent of mine openings, number of active levels and amount of equipment, a demonstration project is proposed for the following purposes:

a) Gain technical experience with the layout, installation and use of the recommended radio system; learn about the propagation characteristics of frequency modulated medium frequency radio at Ruttan Mine.

b) Confirm and quantify the economic and safety benefits of a radio communication system underground.

The radio system recommended for general mine-wide communication at Ruttan Mine is the Montan-Forschung system. This system is selected because:

- Power output is low (0.5 watts E.R.P.) and units are intrinsically safe and non-hazardous near electric detonators.

- The antenna network is an inexpensive single 3.31 mm^2 (#12 A.W.G.) wire which can be readily expanded. This wire represents the only slight disadvantage of the Montan system compared with some other systems that operate totally by induction into existing mine cables. But areas within Ruttan Mine do not have electrical cables. The medium frequency (approx. 450 KHz) system does have the ability to inductively couple onto whatever metal pipes, cables, or other conductors are available in drifts.

- Frequency modulated radio provides superior transmission compared with amplitude modulated, single-side-band units of equivalent power.

- The underground portable units are among the most compact and rugged on the market. They are also very easy to use - simply a P.T.T. (push-to-talk) switch on the unit or on a hand mike - there are no squelch controls and volume gain is automatic. Base/repeater units and vehicular units are also available for various power supply voltages and can be equipped with loudspeakers. Different tones signal beginning and ending of transmissions so the system is very "user friendly" and could be used for code calls as well.

- The system is price competitive with other mine radios.

- The Montan system can be adapted for transmitting control signals and data, even from mobile equipment. It is feasible to incorporate a mine-wide monitoring system capable of automatic transmission of data even from mobile equipment to a computer such as an IBM PC microcomputer. This option will be discussed separately.

The proposed demonstration of voice radio communication at Ruttan Mine consists of the following:

1 - base/repeater unit installed in the garage on 430 level

5 - portable units to be used by personnel working in isolated areas, operating and maintenance supervision

4 - vehicular units to be installed on critical production equipment such as LHD's and trucks to be identified by Ruttan Mine personnel

- wiring extending through to active production areas on at least two other levels in the "Upper Mine"

The demonstration should take place over a period of at least three months, during which time, an accurate log of radio usage, time-saving, system maintenance, etc. is kept and analysed by the project leader. The estimated initial cost of the pilot or demonstration project is shown in Table 7.2

Table 7.2

Estimated Cost of Pilot Project for Voice Communications

Recommended system: Montan-Forschung	
1 - base/repeater unit	$8,100
4 - vehicular units	5,400
5 - portable units	7,500
5 - spare battery packs	650
1 - charger system for batteries	2,900
Impedance meters, terminal resistors, etc.	600
Sub Total	$25,150
Duty (if applicable)	2,700
F.S.T. (if applicable)	3,100
P.S.T. (if applicable)	1,850
Shipping Expenses	900
Single wire antenna (1500m, est.)	200
Misc. Mounting Hardware	100
Sub Total	$34,000
Montan-Forschung design engineer to commission pilot system	5,000
Installation of antenna and mounting vehicular units, etc.	10,000
TOTAL	$49,000

The cost per unit associated with the pilot project is considerably higher than the cost per unit of full-scale system. This is because there are a number of once-only costs associated with the pilot system such as design engineer services, learning curve effects, base/repeater station etc. It is recommended that the base unit be installed on 430 level not only because it is best suited for the pilot project

but also because it is central to the mine. While more accurate costs can be determined during the pilot project, Table 7.3 shows the estimated additional cost for the full-scale system. The extent of the system is based on discussions with Sheritt Gordon personnel in which the size of the mobile equipment fleet was indicated, projected manpower, and proposed level plans for the "Lower Mine" were described. The actual number of units and mix of portable and vehicular units is of course subject to revision. The total is also subject to CANMET budget constraints.

Table 7.3

Estimated Cost to Upgrade Pilot Project to Full Scale System

26 - Additional vehicular units (supervisor's jeeps, LHD's, jumbos and other critical vehicles)	$ 46,800
4 - "Dispatcher" style units (for strategic locations such as supply clerk, shops, refuge station, wicket)	4,400
13 - Additional portable units (for spares, isolated workers, personnel without ready access to vehicle with radio)	19,400
13 - Additional spare batteries	1,700
2 - Additional charging units	5,800
Sub Total	78,100
Duties, F.S.T., P.S.T. (if applicable)	19,300
Shipping Expense	4,000
Single Wire Antenna (4500 m)	600
Sub Total	102,000
Installation of vehicle units, antenna, etc.	25,000
TOTAL	$127,000

Table 7.4 Summary of Cost Estimates for Voice Communication Systems

	Hardware	Installation	Total
Shaft System	$15,000	$2,000	$17,000
General Mine System-Pilot Project	34,000	15,000	49,000
General Mine System-Upgrade to Full Scale	102,000	25,000	127,000
			193,000
Contingencies			12,000
TOTAL INSTALLED COST			$205,000

Note: Because of the R & D nature of this project, it may be eligible for favourable tax treatment or exemption from certain duties and taxes. However, the price is subject to change due to variation in currency exchange rate and Canadian distribution costs.

7.3 Data Transmission Option

In addition to the voice communication system, a pilot/demonstration project for data transmission is presented for consideration. It is suggested that this demonstration be conducted concurrently with the voice communication pilot project. The proposal would consist of components utilizing much of the hardware that would be installed for the voice system (ie. same base/repeater unit but at alternate frequency of 290 KHz and antenna wire). The demonstration would consist of one on-board data terminal with the data transmitter/receiver mounted on a critical LHD or truck, an interface base/computer to convert the data to a form useable by an IBM PC or AT with appropriate software and, optionally, one infra-red vehicle locater. For the purpose of the demonstration, some on-line as well as operator-inputted information could be used. Engine oil temperature and pressure and engine hours could be monitored and automatically recorded on the Maintenance Department's IBM microcomputer on surface. The infra-red locating device could automatically indicate whenever, say, the LHD arrives at a given drawpoint, or when a truck passes a given location in the main haulageway or arrives at the orepass. (A full-scale data system could be capable of monitoring the location of individual vehicles at all times). The operator could enter, on a small keypad, specific data such as bucket count, 'machine is down', and other daily reporting requirements. Such a computerized data-gathering system could be combined with the "MAG" software package already in use at Ruttan Mine to achieve a fully-integrated maintenance analysis system. Other data transmission modules could be used for microprocessor-based remote monitoring and control of fans,

heaters, compressors, pumps, rock mechanics instrumentation, etc.

The cost of the mobile data system demonstration is estimated in Table 7.5.

Table 7.5

Estimated Cost of Mobile Data Transmission Demonstration Option

Prerequisite: Voice communication pilot project installed as proposed	
1 - Mobile Data Terminal	$ 2,450
1 - Data Transmitter/Receiver	1,050
1 - Infra-red Position Code Receiver	1,200
1 - Infra-red Position Code Transmitter	800
1 - Interface Base/Computer	5,000
Software for IBM - Microcomputer	6,100
Sub Total	16,600
Duties, F.S.T., P.S.T. (if applicable)	2,100
Shipping Expense	300
Sub Total	19,000
Montan-Forschung design engineer to commission demonstration system(if done concurrently with voice pilot system)	1,800
Installation	3,200
TOTAL	$24,000

It must be noted that the majority of the demonstration project costs would be 'once-only' (ie. interface computer, software, engineering services, and most of the installation costs). Also, once a network of position code transmitters is established, each one could be used for all vehicles passing by a given position. For example, a network of 8 position code transmitters may be established for which there may be 30 vehicles equipped with position code receivers. The incremental cost of equipping additional vehicles with data transmission capability would include mobile data terminal, data transmitter/receiver, and position code receiver at less than $5,000 per vehicle (plus applicable taxes and approximately two manshifts installation time).

APPENDIX A

UNDERGROUND RADIO COMMUNICATION AND MONITORING SYSTEM SUPPLIERS

I. LEAKY FEEDERS SYSTEMS

1. Andrew Antenna Company Limited
   606 Beech Street
   WHITBY, Ontario L1N 5S2 Tel. 416-668-3348

2. NEI Mining Equipment Canada
   55 Harbour Drive
   Sydport Industrial Park
   P.O. Box 967
   SYDNEY, N. S. B1P 6J4 Tel. 902-564-5592

3. Minelec Ltd.
   2610 Dunwin Drive
   MISSISSAUGA, Ontario L5L 1J5 Tel. 416-828-1520

II. CTV SYSTEMS

4. International Aeradio Ltd.
   Thornhill, Ontario Tel. 416-731-1300

III. MEDIUM FREQUENCY SYSTEMS

5. Montan-Forschung
   Dr. Hans Ziller
   Postfach 567, 4010 Hilden Tel. 011-49-2103-6822
   West Germany

6. Nagano Japan Radio Company
   Distributor: Blackwood Hodge Equipment Ltd.
   404 Falconbridge Road
   SUDBURY, Ontario P3A 4S2 Tel. 705-566-3511

7. Silec
   Distributor: El-Equip
   54 Ontario Avenue
   ELLIOT LAKE, Ontario P5A 1Y1 Tel. 705-848-5748

8. Plessey Radio Systems
   Martin Road
   Westleigh, Havant, Hampshire
   United Kingdom PO9 5DH Telex 86227

APPENDIX A (Cont.)

IV. SHAFT COMMUNICATION SYSTEMS

1. MSA Canada Inc.
   148 Norfinch Drive
   DOWNSVIEW, Ontario M3N 1X8 Tel. 416-667-9400

2. Femco/National Mines Services (Canada) Ltd.
   378 Whittaker St.
   SUDBURY, Ontario P3C 3X9 Tel. 705-673-1533

3. Funke & Huster
   Postfach 101253
   4300 Essen 1
   West Germany

V. MONITORING SYSTEMS

1. Conspec Controls Incorporated
   901 Fuhrmann Avenue
   BUFFALO, New York
   USA 14203 Tel. 716-854-4769

2. Outokumpu Instruments Canada Limited
   1655 Sismet Road
   Unit 7
   MISSISSAUGA, Ontario Tel. 416-671-3304

3. Gould Electronics (Canada) Limited
   6630 Campbello Road
   MISSISSAUGA, Ontario
   L5N 2LB Tel. 416-821-8200

4. Montan-Forschung
   Dr. Hans Ziller
   Postfach 567, 4010 Hilden
   West Germany Tel. 49-2103-6822

5. Modudata System Limited
   Box 365
   NEWMARKET, Ontario Tel. 416-773-6414

GENERAL REFERENCES

I. UNDERGROUND RADIO VOCAL COMMUNICATION

1. Conference on Automation in Coal Mines, Luxembourg, May 29-31, 1972. Edited by the Directorate-General Scientific and Technical Information and Information Management, Dec. 1973.

   - Liegeois, R.: Telecommunication Underground, pp. 27.

   - Steudel, I.: Telecommunication and Remote Control at the Face, New Developments in the Use of Radio in German Coal Mines, pp. 38.

   - Martin, D.J.R.: A Practical VHF Radio System for Complete Coverage of the Mine, pp. 64.

   - Belugou, P.: Telecommunications and Remote Control in District and on Working Faces, Some French Achievements, pp. 45.

2. Chufo, R.L. and H. E. Parkinson: An Experiment in Wireless Communications and Environmental Monitoring in Metal Mines. International Conference, Remote Control and Monitoring in Mining Oct. 11-13, 1977, Birmingham, England, published by the National Coal Board, pp. 31.

3. Morgan, M.D.: A New U/G Radio Communication System (Mine #1, Inland Steel Coal Company), Canadian Mining Journal, July, 1982.

4. Sullivan, A. M. & J. Cawley: Communication Improves Mine Safety, Coal Age, Oct. 1980, pp. 154.

5. Babik, P. & R. Jones: CATV for U/G Radio Communication, Canadian Mining Journal, January, 1983, pp. 76

6. Everell, M. D. & R. Tervo: Some Recent Applications of Radio Communications in Underground Mining, Canadian Mining Journal, April 1975, pp. 55.

7. Cory, T. S. and R. J. Mahany: Propagation of EM Signals in Underground Metal/Non-Metal Mines, U.S.B.M. Open File Report (OFR 126-83), PB83-234666 August, 1981.

8. Martin, D.J.R.: Leaky Feeder Communication in Tunnels, Wireless World, July 1982, pp. 33-37.

9. Nickel, J. V. & J. S. Brown: Radiax T.M. Coaxial Cable and Portable Underground Communications Systems; Paper Presented at the First W.V.U. Conference on Coal Mine Electrotechnology at West Virginia University, August, 1972.

10. Tervo, R., M. S. Taylor & R. W. Jones: VHF/UHF Communications Using a Slotted Coaxial Cable, Canadian Mining Journal, August, 1973.

11. Newmann, T. E.: Mine Communication Systems (Radio) At Brunswick Mining; 4th CIM M/E Conference, pp. 182-186.

12. Hurley, P. J.: The Introduction of a Radio Communication System Underground at Brunswick Mining. CIM District I Meeting - Fredericton, N.B., Sept. 1982.

13. Stiefel, A. I.: Underground Communications and Information Systems, Mining Congress Journal, July 1980, pp. 31 - 41.

14. Mining and Smelting in Japan, Mining Magazine, November 1984, pp. 418-419. (Fukasawa Mine)

15. Mining Research Staff - U.S.B.M.: Underground Mine Communications:

Part 1	Mine Telephone Systems	IC8742,1977
Part 2	Paging Systems	IC8743,1977
Part 3	Haulage Systems	IC8744,1977
Part 4	Section-to-Place Comm.	IC8745,1977

16. Dobroski, H. Jr. and L. G. Stolarczyk: Radio Communication Improves Productivity, Safety, Canadian Mining Journal, July, 1983, pp.26-29.

17. Cawley, J. C. & R. A. Isberg: The Design and Implementation of a UHF Radio System Using Distributed Antennas, Passive Reflectors and Two Way Signal Boosters in A Room and Pillar Limestone Mine, T.P. #1484.

18. Isberg, R. A., H. Kramer and D. A. Parrish: The Implementation of UHF Radio Communications and ECTV Monitoring System in a Room and Pillar Metal/Nonmetal Mine, Final Report. National Technical Information Services pp. 82-116674, March 1981, p.131.

19. Staff, USBM: Underground Mine Communications, Control and Monitoring, IC8955, 1984.

20. Reeves, J.D.: Underground Communication System. Report submitted to MIROC by Falconbridge Limited, December 1983.

21. Development in SA of World's First Practical Underground Radio, Coal Gold and Base Minerals of Southern Africa, July 1978, pp. 15.

22. Murphy, J.N. et al: Underground Mine Communications. Proceedings of the IEEE, Vol. 66, No. 1, 1978.

23. Noble, E. M.: Modern Communication Course, H.W. Sanrs & Co., Indiana, 1962.

24. Fink et al: Standard Handbook for Electrical Engineers, 10th Edition, McGraw Hill, 1968.

25. Reuters, H.: Die Leitungsgebundene Ausbreitung von Fvnkwellen auf offenen Wellenleitvn in Schact, Gluckauf-Forschungshefte, 44 (1983) H.#.

26. Olaf, J. etal 1984: Die Leitungozebundene Ausbreitung Elektranognetischen Wellen unter tage Glukauf 120 (1984) Nr. 23.

27. Reuter, H., 1983: Die Leitungozebundene induktive Ausbreitung von Funkivellan in Schacht, Glukauf-Forschungshefte 44 (1983) page 162/170.

28. Nelson, T.V., 1980: Propagation of M.F. signals along mine tunnels containing axial wire and water trough. Electronics Letters, Vol. K, No. 22 (1980) page 834/836.

II. UNDERGROUND DATA COMMUNICATIONS

1. Arthur, D. Little, Inc.: Development of a Through-the-Earth Monitor System, Bureau of Mines Open File Report 99-81. PB81-237646, December 1980.

2. McAuley, T. J. & I. K. Smith: A 2000 Channel Mine-wide Data Acquisition System, Broken Hill Conference, 1983, published by the Australian Institute of Mining and Metallurgy, pp. 257.

3. Sheeran, C. T. and J. C. Franklin: Microcomputer-Based Monitoring and Control System with Uranium Mining Application, Bureau of Mines Information Circular/1984,IC8981.

4. Vogt, George: Communication and Data transmission in Deep Mines at the Birmingham International Conference. Gluckauf + Translation, 114 (1978).

5. Wright, H. A., R. Madden & M. N. Rubin: Guidelines for Environmental Monitoring in Underground Coal Mines, A USBM Minerals Research Contract Report, Phase I Report, June 1982.

6. Welsh, J. H., Computerized, Remote Monitoring Systems for Underground Coal Mines - Fires and Explosive Atmosphere, USBM IC8897/1982 - Faults in Power Systems, USBM IC8944/1983.

7. Kaimar, R. M., Reliability of Computerized Mine - Monitoring Systems. USBM IC8882, 1982.

8. Boylen, R. S., A Remote Air Analysis System for Early Warning of an Underground Fire, The Aus. I.M.M. Conference, Broken Hill N.S.W. July 1983, pp. 437-439.

9. Metcalf, C. A. and K. L.Billhartz: Mine Wide Monitoring System at San Manuel, Paper presented at Western Mining Industry Electrotechnology Conference, Reno, Nevada, Sept. 1981.

10. Ellie, G. and Tervo: Televigile - An Automated System for Remote Surveillance and Information Gathering in Mines, The Annual Western Meeting C.I.M., Saskatoon, Oct. 1972.

11. Beronsky, B., F. DuBreuli and J. Yingling: Evaluation of Computer-Based Mine Monitoring and Control at Barnes and Tucker Mine 20, The Seventh WVU Mining Electrotechnology Conference, West Virginia University, July 1984, pp.108-121.

12. Jackson, D.: FMC Mine Adopts Monitoring System, Coal Age, Jan. 1979, pp. 124-125.

13. Dobroski, H. Jr. & L. G. Stolarczyk: Control and Monitoring via Medium Frequency Techniques and Existing Mine Conductors, The Seventh WVU Mining Electrotechnology Conference, West Virginia University, July 1984, pp.139-152.

14. Brightman, J.R.: Application of Microcomputers to Mine Automation and Safety, World Mining Equipment, April 1984, pp. 37-40.

15. Brezovee, D.: Computer Monitors Mine Conditions, Coal Age, Aug. 1981, pp. 56-62.

16. Bordin, D. A.: The M.I.R.O.C. Ventilation Monitoring System at Kidd Creek Mines Ltd., Paper Presented at the Fifty-Second Annual Technical Sessions of Mines Accident Prevention Association of Ontario, May 1983.

17. Tregelles, P. G.: Micro-Electronics in Mining Operations, The Mining Engineer, March 1984, pp. 401-405.

III. OTHER

1. Ikeman, H.: Application of Fibre Optics in the Mining Industry, CIM Bulletin, Septemer 1984, pp. 41-43.

2. Conduit, A. J.: Optical Fibres and the Communications Revolution, The AIMM Bulletin, Feb. 1984, pp. 13-15.

3. Miller, J. W. & A. J. Szanto: Fibre Optics in the Mining Industry, CIM Reporter April 27, 1982, pp. 26.

4. Bendersky, D., J. E. Golob, V. W. Klein and D. R. Keyes: Fiberoptics Technology for Underground Mine Communication, Bureau of Mines Open File Report 77-82, PB83-175562, Jan. 1982.

IV. SAFETY REGULATIONS

1. Manitoba Mining Act.

2. Ontario Mining Act.

3. Test Apparatus for Blasting Cap Hazards Due to Radio Frequency (R.F.) Radiation.

4. Electric Blasting Cap Hazards from Radio Frequency Radiation.

5. CSA Standard Z-65 Appendix C: Electric Blasting Caps.

6. CSA Standard Z-65 Appendix D: Radio Frequency Hazards to Electric Blasting Cap.